NASA Structures & Materials

Strategic Partnership Plan

A NASA Center of Excellence

AUGUST 2003

Executive Summary

This report presents a Structures and Materials Strategic Partnership Plan for NASA. The plan documented herein is the result of an Agencywide planning activity led by the Structures and Materials Competency Office at Langley Research Center (LaRC). A strategic partnership has been established among the four (4) NASA Field Centers, shown in Figure 1, with dedicated structures and materials capabilities.

The NASA Structures and Materials Strategic Partnership (SMSP) will provide the leadership for coordination, planning, advocacy, and assessment of the structures and materials research and technology development activities throughout the Agency. The SMSP will promote the development of new material systems and processes, innovative structural mechanics and dynamics design and analysis methods, experimental techniques, and advanced structural concepts through technology validation for aircraft, space transportation vehicles, science instruments and spacecraft. The SMSP will address technology challenges to enable more affordable, lighter weight, higher strength and stiffness, safer, and more durable vehicles for subsonic, supersonic, and sustained hypersonic flight, earth and other planetary atmospheric entry, and for spacecraft flight throughout the solar system.

The SMSP will implement the following five specific functional responsibilities:

1. Conduct a periodic assessment of the current technical capabilities in relation to future Agency missions and technology requirements.

2. Maintain and enhance the preeminent technical capabilities distributed throughout the Agency.

3. Proactively participate in planning future Agency programs.

4. Serve as the primary point-of-contact for requests for structures and materials technical information and for requests to participate in urgent investigations of critical problems.

5. Build strategic alliances / partnerships with all NASA Field Centers, other agency technical centers of excellence, industry, academia, other Government Agencies, and international partners.

The SMSP will be led by the Structures and Materials Competency Office at the Langley Research Center with strategic partnerships established among the 4 NASA Field Centers, forming the Structures and Materials (SM) Community. The SMSP will provide the strategic leadership required to implement the functional responsibilities of the SMSP. The SM Community will be responsible for maintaining and enhancing the preeminent technical and programmatic expertise and ground test facilities and laboratories distributed throughout the Agency. The SM Community will develop and maintain partnerships with industry, academia, and other Government Agencies to leverage external programs and resources to achieve NASA strategic objectives. The SMSP will coordinate with the other NASA centers of excellence and key NASA Headquarters Offices, as appropriate, to effectively and efficiently meet the research and technology needs of all the NASA Strategic Enterprises.

Table of Contents

List of Figures

List of Tables

NASA
Structures and Materials Strategic Partnership Plan
An Agency Center of Excellence

1.0 Introduction

This report presents a Structures and Materials Strategic Partnership Plan for NASA. The plan documented herein is the result of an Agencywide planning activity led by the Structures and Materials Competency Office at Langley Research Center (LaRC). A strategic partnership has been established among the four (4) NASA Field Centers, shown in Figure 1, with dedicated structures and materials capabilities.

2.0 Mission

The Structures and Materials Strategic Partnership (SMSP) will provide the leadership for coordination, planning, advocacy, and assessment of the structures and materials research and technology development activities throughout the Agency. The SMSP will promote the development of new material systems and processes, innovative structural mechanics and dynamics design and analysis methods, experimental techniques, and advanced structural concepts through technology validation for aircraft, space transportation vehicles, science instruments and spacecraft. The SMSP will address technology challenges to enable more affordable, lighter weight, higher strength and stiffness, safer, and more durable vehicles for subsonic, supersonic, and sustained hypersonic flight, earth and other planetary atmospheric entry, and for spacecraft flight throughout the solar system.

The SMSP will be led by the Structures and Materials Competency Office at the Langley Research Center with strategic partnerships established among the 4 NASA Field Centers, forming the Structures and Materials (SM) Community. The SMSP will provide the strategic leadership required to implement the functional responsibilities of the SMSP. The SM Community will be responsible for maintaining and enhancing the preeminent technical and programmatic expertise and ground test facilities and laboratories distributed throughout the Agency. The SM Community will develop and maintain partnerships with industry, academia, and other Government Agencies to leverage external programs and resources to achieve NASA strategic objectives. The SMSP will coordinate with the other NASA centers of excellence and key NASA Headquarters Offices, as appropriate, to effectively and efficiently meet the research and technology needs of all the NASA Strategic Enterprises.

3.0 Vision

The SMSP is the Agencywide technical conscience for structures and materials technologies and fulfills a strategic leadership function. The Agency will benefit from the SM Community through the effective and efficient utility of the comprehensive inventory of technical capabilities distributed across the Agency, coordination of these capabilities, leading and participating in strategic planning, and maintaining and enhancing the preeminent Agency core competency in structures and materials.

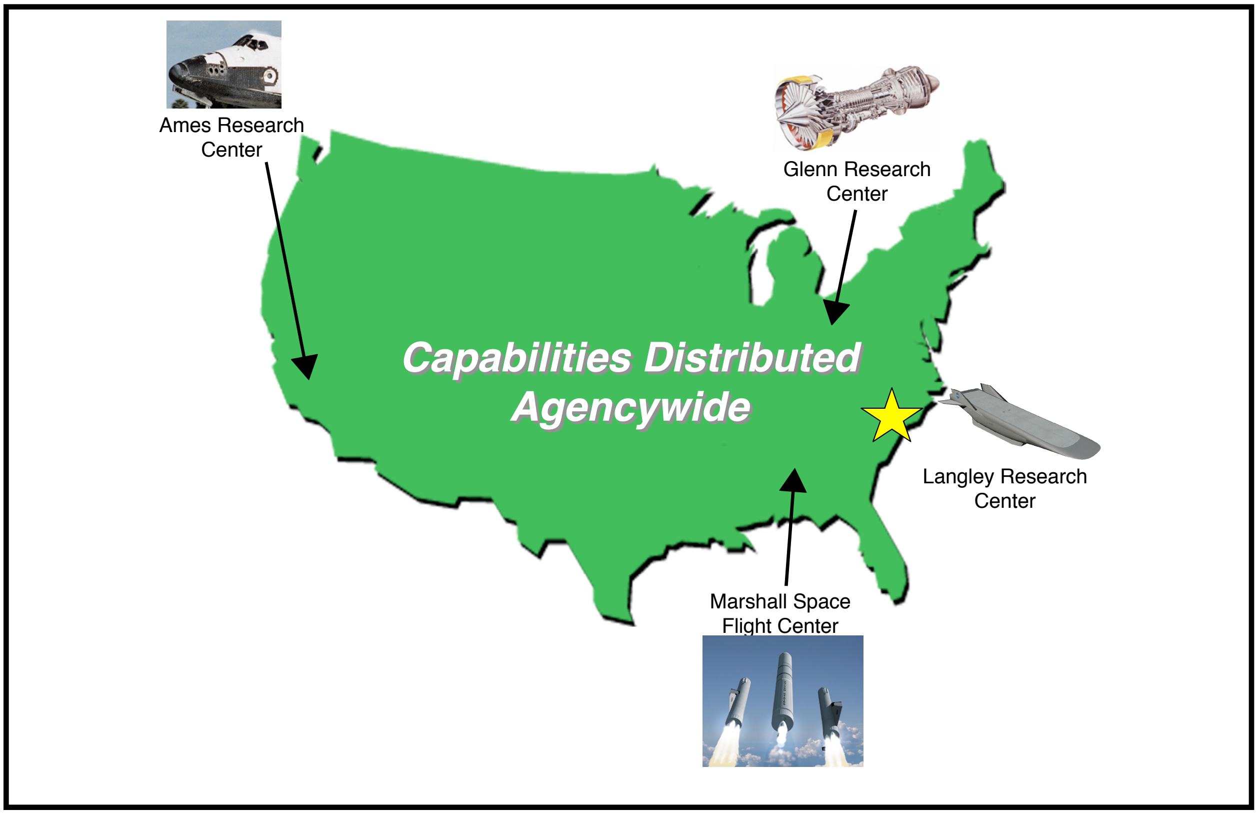


Figure 1. NASA Center Partners in the Structures and Materials Community

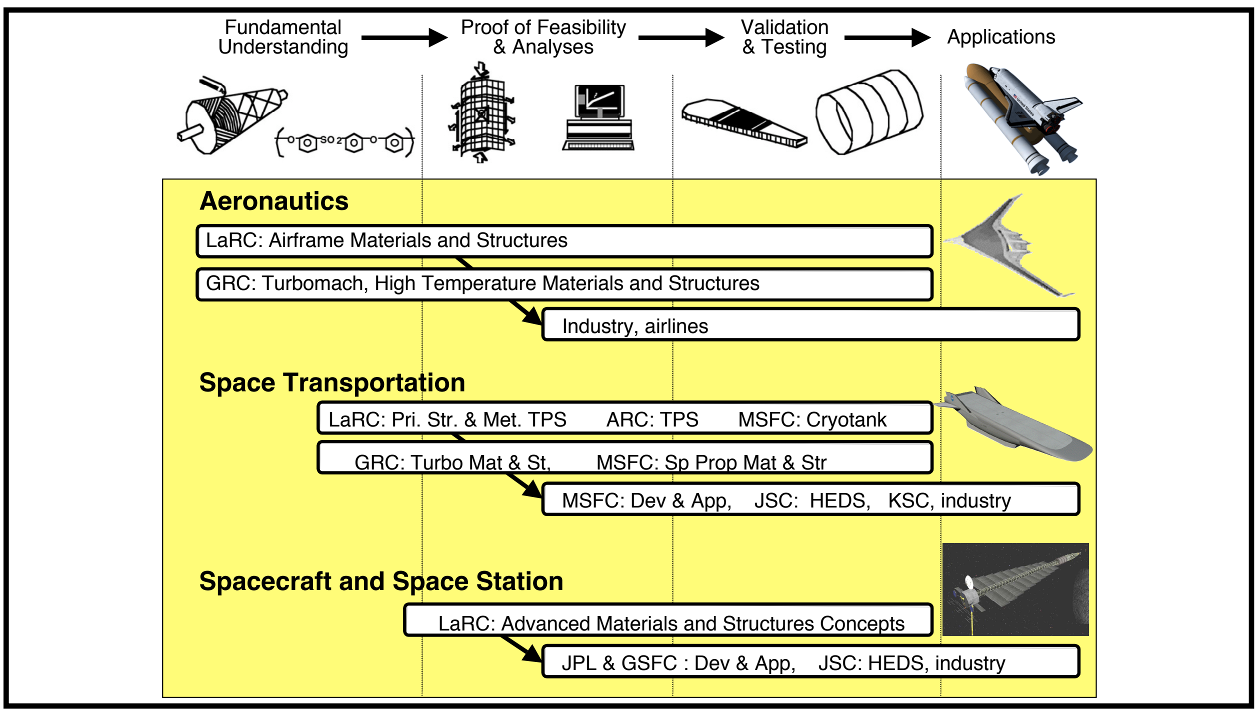


Figure 2. Technology Scope

4.0 Technology Scope

The technology scope of the SMSP, illustrated schematically in Figure 2, includes research programs, technology development and demonstration programs; and the application of structures and materials technologies to NASA atmospheric flight missions, space launch, space and earth sciences missions, the Space Station and future human exploration missions.

The technology scope encompasses the airframe and engine of subsonic, supersonic, and hypersonic aircraft; primary structure, cryotank, thermal protection systems, and propulsion systems of space transportation vehicles; space science instruments, and power and structural components of spacecraft; the Space Station; earth and other planetary atmospheric entry vehicles, and human space/planetary transfer stages/landers/habitats.

The strategic partnership among the 4 NASA Field Centers is based on the following specific, unique technology application focus at each Center:

Ames Research Center: advanced ceramic thermal protection materials and systems (TPS) for space transportation vehicles, CFD modeling and analysis and experimental testing of existing TPS and advanced TPS concepts

Langley Research Center: airframe primary structure; primary structure, cryotank, and metallic thermal protection systems of space transportation vehicles; and advanced concepts for spacecraft and space science instruments

Glenn Research Center: turbomachinery for aircraft engines; high temperature materials for space transportation vehicles; aerospace power; power for LEO, MEO, and GSO planetary and interplanetary spacecraft, and space experiments

Marshall Space Flight Center: primary and secondary structure, cryotanks, and TPS/insulation for integrated space transportation and propulsion system structure; and advanced space instruments, payloads, and subsystems

5.0 Inventory of Agencywide Technical Capabilities

A detailed inventory of the Agencywide structures and materials technical capabilities is given in the Appendix. The inventory includes a listing of the disciplinary technical skills relative to specific applications, description of the dedicated structures and materials facilities and laboratories, and recent accomplishments for each Center in the SM Community. A summary of these skills is given in Table 1. Over 100 dedicated facilities and laboratories are described in the inventory. A summary of these experimental capabilities are given in Table 2. The structures and materials workforce is supporting all 4 NASA Enterprises and 71 programs are listed in the inventory. A summary of the civil service workforce is given in Table 3. Examples of recent structures and materials technical accomplishments from each NASA Center is also given in the Appendix.

Table 1. Disciplinary Technical Skills

Laboratories and Facilities	LaRC	GRC	ARC	MSFC
Polymers and composites	R&D	R&D		D, S
Metals and composites	R&D	R&D		R&D, S
Ceramics, refractory mat'l and composites	R&D	R&D	R&D	D, S
Mat'ls characterization, analysis, and properties	R&D, S	R&D, S	R&D	R&D, S
Durability and mission simulation	R&D	R&D		R&D, S
Fatigue and fracture	R&D	R&D	R&D	R&D, S
Tribology (coatings, lubricants, & bearings)		R&D		R&D, S
Nondestructive evaluation sciences and NDE/I	R&D, S	R&D,S		R&D, S
High temperature, high heat flux facilities	R&D	R&D	R&D	D, S
Large component structural test facilities	R&D	R&D		D, S
Structural dynamics, vibration, and acoustics	R&D	R&D,S		D, S
Thermal vacuum and space simulator facilities		R&D,S		R&D, S
Electromechanical, MEMS/MOMS, & actuators	R&D			D, S
Aerothermodynamic structures facilities	R&D		R&D	D, S
Spacecraft / instrument fab, assembly & testing	D, S	D, S		D, S
Unique facilities with specialized capability	TDT ALDF COLTS Nano/bio technology	Turbomach Comp Test Complex, Nano/bio technology	Arc Jet Complex, Nano/bio technology	Large tests, Turbopump LOX & H_2, outgassing, space environ. effects & large thermal vacuum

R = research
D = technology development and demonstration
S = support of flight hardware

Table 2. Facilities and Laboratories

Technical Capabilities	LaRC	GRC	ARC	MSFC
New materials development	MPC^T R^f, R^a	$M^TP^TC^T$ R^f, R^a	C^T R^f, R^a, D	
Materials processing & fabrication technology	MPC^T R^f, R^a	$M^TP^TC^T$ R^f, R^a	C^T R^f, R^a D, S	$M^TP^TC^T$ R^a, D, S
Materials characterization & failure analysis	MPC^T R^f, R^a, S	$M^TP^TC^T$ R^f, R^a, S	C^T R^f, R^a D, S	$M^TP^TC^T$ R^a, D, S
Materials durability & fatigue and fracture	MPC^T R^f, R^a	$M^TP^TC^T$ R^f, R^a		$M^TP^TC^T$ R^a, D, S
Tribology (coatings, lubricants, & bearings)		R^f, R^a		R^a, D, S
Nondestructive evaluation sciences & NDE/I	R^f, R^a D, S	R^f, R^a		R^a, D, S
Structural mechanics, strength, & design meth.	R^f, R^a D, S	R^f, R^a		R^a, D, S
Dynamics, vibration & modal analysis & tests	R^f, R^a	R^f, R^a	MPC	R^a, D, S
Structural acoustics methodology & testing	R^f, R^a	R^f, R^a		D, S
Aeroelasticity analysis methods & testing	R^f, R^a, D	R^f, R^a		
Flight hardware design, fabrication, & testing	D, S		D, S	D, S

M = metallic alloys and composites (M^T = high temperature propulsion materials)
P = polymers and composites (P^T = high temperature propulsion materials)
C^T = high temperature ceramic and refractory materials and composites
R^f = fundamental research, and R^a = applied (focused) research
D = technology development and demonstration
S = innovative engineering for mission support

Table 3. FY03 Structures and Materials Workforce

FTE's	LaRC	GRC	ARC	MSFC
Civil Service	273	301	55	□51

6.0 Functional Responsibilities and Implementation Plans

The Structures and Materials Strategic Partnership (SMSP) will implement the following five specific functional responsibilities

1. Conduct a periodic assessment of the current technical capabilities in relation to future Agency missions and technology requirements.

2. Maintain and enhance the preeminent technical capabilities distributed throughout the Agency.

3. Proactively participate in planning future Agency programs.

4. Serve as the primary point-of-contact for requests for structures and materials technical information and for requests to participate in urgent investigations of critical problems ("911 calls").

5. Build strategic alliances / partnerships with all NASA Field Centers, other technical centers of excellence, industry, academia, other Government Agencies, and international partners.

The tasks required to implement each responsibility are described in the following sections.

6.1 Conduct a periodic assessment of the current technical capabilities in relation to future Agency missions and technology requirements.

A process has been developed for conducting the periodic assessment of the current technical capabilities distributed throughout the SM Community. This process is outlined in the process flow diagram shown in Figure 3. The SM will implement the following specific tasks:

1. The SMSP will compile and publish an inventory of the Agency's structures and materials capabilities. Each Center will provide the following data:
   - Technical capabilities,
   - Description of facilities and laboratories,
   - Workforce (FTE's),
   - Recent accomplishments and problems solved,
   - Future Agency missions/needs and technical requirements ("technology pull"),
   - Examples of "technology push" that enables a future Agency mission.

2. Each Center will conduct a self-assessment of strengths, weaknesses, and gaps with respect to Enterprise goals and objectives.

3. The SMSP will coordinate the Center self-assessments, identify overarching themes, develop list of deficiencies, and benchmark NASA capabilities to those of outside organizations, as appropriate.

4. The SMSP will lead the development of recommendations to address deficiencies, and proactively advocate appropriate implementation of the recommendations.

5. Each Center will develop a Structures and Materials Facilities and Laboratories Brochure(s) suitable for public dissemination.

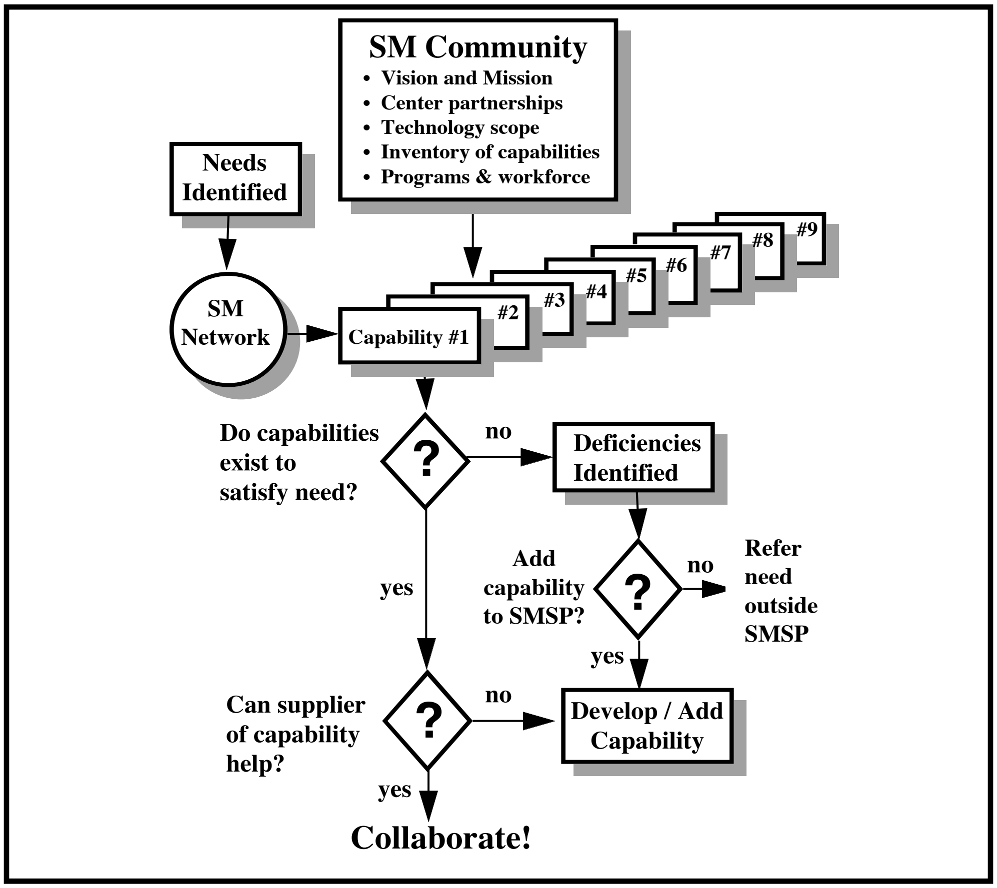


Figure 3. Periodic assessments of the current technical capabilities

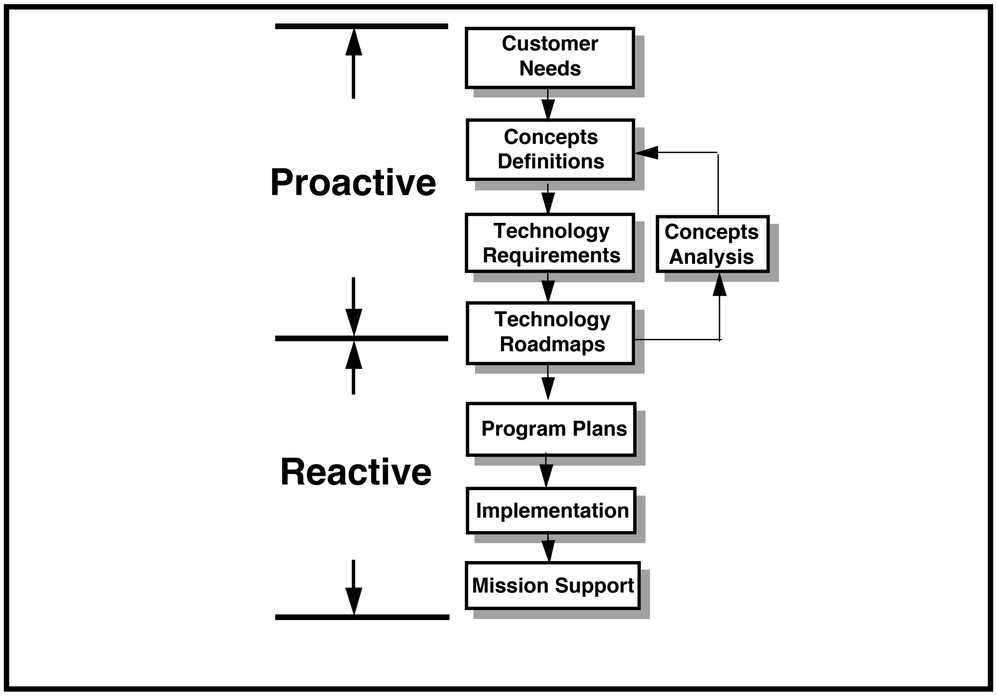


Figure 4. Notional diagram of the process for program development

6.2 Maintain and enhance the preeminent technical capabilities distributed throughout the Agency.

The responsibility to maintain and enhance the preeminent technical capabilities distributed throughout the Agency resides with the line management at each participating Center. The SMSP will establish Working Groups in specific technical areas that cross-cut the structures and materials community. The purpose of these Working Groups will be to discuss common problems, share experiences, and form partnerships where cooperative activities are mutually beneficial. It is anticipated that several Working Groups will be established as standing committees to address the maintenance and enhancement of technical skills and expertise. However, Working Groups to address the enhancement of Facilities and Laboratories will only be established when the need arises from the periodic assessment of current technical capabilities. The SMSP will:

1. Coordinate the establishment of Working Groups by conducting a canvas of the SM Community to obtain a list of existing relevant Working Groups, identify candidate technical areas for new Working Groups, and gage the interest in participating. (Table 4 contains a list of some of the existing NASA Working Groups.)

2. Initiate a discussion with existing Working Groups that may be appropriate to facilitate the objectives of the SMSP.

3. Where sufficient interest exists to create a new Working Group, the SMSP will lead the development of a charter, solicit names of the members from the interested Centers, and a kick-off meeting will be organized.

4. The SM Community will voluntarily participate in those Working Groups that directly benefit the participating Centers.

6.3 Proactively participate in planning future Agency programs.

A notional diagram of the NASA process for program creation, implementation, and mission support is shown in Figure 4. The SMSP will be proactive in planning future programs and Agency missions. This proactive role will help insure that all future programs are planned with an appropriate structures and materials content. Also, visionary plans for long-term developments in structures and materials will be advocated as examples of technologies that can enable future Agency missions that are not currently conceived. The SMSP will:

1. Coordinate the support for planning future programs as requests are received and opportunities identified.
2. The SM Community will voluntarily participate in the planning activities as requests/opportunities arise.
3. The responsibility to communicate throughout the SM Community the information regarding requests and opportunities is jointly shared by the SMSP and the SM Community members.
4. Engage in regular discussions with key personnel in Enterprise and Program Offices. These discussions are intended to be informational in content. (Advocacy for implementing recommendations is part of the responsibility for conducting periodic assessments of current technical capabilities.)
5. Organize and participate in workshops of specific technical issues of interest to the SM Community. Emphasis will be given to the long-term view, especially where structures and materials has an opportunity to provide a “technology push” that enables a future Agency mission. (Participation on the organizing committee and in the workshop is voluntary).

Table 4. Existing Disciplinary Working Groups

- NASA NDE Working Group
- NASA Materials and Processes Working Group
- NASA Fracture Control Panel
- NASA Design, Analysis, Test, and Verification Working Group
- Engineering Standards Steering Committee
- NASA Reliability Board
- Vibroacoustics Standards Panel
- NASA Space Mechanisms Working Group
- NASA Microdynamics Working Group
- NASA Structural Dynamics Working Group
- Telerobotic Intercenter Working Group
- NASA Structures Probabilistics Working Group
- Loads Standards Panel
- Life Prediction of Ceramic Matrix Composites for RLV Applications
- Fracture Toughness Testing of Lithium-Aluminum Shuttle Tank Replacement Materials
- Characterization of NASA-derived Advanced Polymeric Materials
- Space Environments and Effects Program: Meteroid & Orbital Debris, Materials & Processes, and Ionizing Radiation Technical Working Groups
- Headquarters S&MA Structures Probabilistics Working Group
- Shuttle Replacement Technology Team
- NASA Operational Environment Team
- ECoA Intercenter Planning Team for the Environmental Initiative
- EOS Structural/Mechanical/Dynamic Loads and Environment Integration of Launch Vehicles
- Structural Stability Research Council
- Synthetic Thinned-Aperture Radiometer (STAR) Development Team
- Structural Stability Research Council
- Langley Smart Structures Technical Committee
- The Technical Cooperation Program on Structures & Dynamics of Aeronautical Vehicles
- Gust Specialists Committee

6.4 Serve as the primary point-of-contact for requests for structures and materials technical information and for requests to participate in urgent investigations of critical problems (“911 calls”).

In order to fulfill the reactive role illustrated notionally in Figure 4, the SMSP will:

1. Respond to requests for technical information as the need arises. The SMSP will use the Directory of Key Personnel (points-of-contact included in the Capabilities Inventory) provided by each Center as a source of referrals when the Office cannot fulfill a request.

2. SMSP coordinate action items with appropriate Centers when requests to participate in urgent investigations of critical problems (“911 calls”) are received.

3. The SM Community will voluntarily participate in “911 calls” at a level judged to be appropriate by the Center(s) receiving the request from the SMSP.

4. Those requests for technical information or “911 calls” that involve multiple Centers will be communicated throughout the SM Community by the SMSP and/or the members of the Community.

6.5 Build strategic alliances / partnerships with all NASA Field Centers, other technical centers of excellence, industry, academia, other Government Agencies, and international partners.

The foundation of the SMSP is the partnership established among the NASA Field Centers. The voluntary participation of all NASA Field Centers in the SMSP partnership is viewed to be essential for success. The NASA community of excellence in structures and materials will benefit from alliances with external organizations. Numerous alliances and partnerships already exist between members of the SM Community and external organizations.

An alliance will be defined as an enduring relationship, connecting parties with common interests (needs), that does not disappear with specific programs. The SMSP will:

1. Canvas the SM Community, compile, and distribute a list of existing structures and materials alliances. (Table 5 contains a list of some of the existing alliances.)

2. The SM Community will identify opportunities for other community partners to join existing alliances.

3. The list of alliances will be evaluated by the SMSP to identify needs not currently fulfilled by the existing alliances.

4. Inform the SM Community of opportunities to form new alliances.

5. The specific actions to form new alliances will be the voluntary initiative of the individual members of the SM Community.

Table 5. Existing Disciplinary Alliances

- Life Prediction of Toughened Ceramics for Heat Engines (NASA GRC, and ORNL)
- T700 Engine Lfie Management Program (NASA GRC, and DoD)
- Guide Consortium on Turbomachinery Forced Response (NASA, DoD, and industry)
- High Cycle Fatigue Program (NASA GRC, and DoD)
- Interagency Advanced Power Group, Thermal Management Subgroup (NASA, DoD, and DoE)
- Carbon-Carbon Spacecraft Radiator Partnership (NASA, DoD, and Industry)
- Shock and Vibration Information and Analysis Center (SAVIAC), Technical Advisory Group (NASA, DoD, DoE, and industry)
- International Structural Optimization Workshop (NASA, ESA, academia, and industry)
- Government Flight Flutter Test Council (NASA, DoD)
- DFRC Flight Test Center Alliance for Flutter Testing (NASA DFRC, and USAFFRC)
- Advanced Composites Working Group Steering Committee (NASA, DoD)
- Mil Handbook 17 Working Group to develop the Specification for SiC/Al MMC (NASA, DoD, FAA, and Industry)
- Mil Handbook 17 Working Group on Specialized Data Development (NASA, DoD, FAA, and industry)
- MMC Working Group for Versailles Project on Advanced Materials and Standards (consortium of laboratories in 8 countries)
- JANNAF Material Properties and Processing Panel (NASA, DoD)
- Integrated High Payoff Rocket Propulsion Technology Materials Working Group (NASA, DoD)
- ISS Materials and Processes Analysis and Integration Team (NASA, industry)
- NASA/USAF Wind Tunnel Alliance: facilities with arc heaters (NASA ARC, JSC, LaRC, and the USAF AEDC)
- NATO Research Test Organization: for TPS and arc jet testing (NATO members)
- Rotorcraft Leadership Team (NASA, Army)
- Rotorcraft HUMS Team (NASA, Army)
- Civil Tilt Rotor Capacity Planning Team (NASA, industry)
- Lower Density Higher Temperature Polymer Matrix Composite Partnership (JPL, USAFRL)
- Composite Structures Design Working Group (NASA, DoD, FAA, and industry)
- Airframe Structural Integrity Working Group (NASA, DoD, FAA, and industry)
- Composite Armor Group (NASA, Army)
- Transportation Research Board: Pavement Surface Properties Committee (NASA, DOT, DoD, and industry)
- AGARD Working Group on experimental steady and unsteady aerodynamic data (AGARD member countries)
- IHPTET/VAATE Steering Committee (NASA GRC and DoD)
- IHPRPT Materials Working Group (NASA MSFC, GRC, DoD, and engine companies)
- Surface Contamination Analysis Technology
- Neutral External Contamination, Electromagnetic Effects & Spacecraft Charging and Ionizing Radiation Technical Working Groups
- National Center for Advanced Manufacturing (NCAM)
- Interagency Structural Ceramics Coordinating Committee (NASA, DOD, DOE, , NSF, DOC)
- Space Shuttle Program Loads Panel

7.0 Agency Leadership Team

The designated center member will serve as the single-point-of-contact for coordinating all tasks that are the responsibility of each Center, listed in Section 8.2 below. The Leadership Team will meet annually to review the SMSP progress, prioritize recommendations, and provide guidance for future activities. The members of the current Leadership Team are:

- Mark Shuart, Director, Structures and Materials Competency, Langley Research Center
- Hugh Gray, Chief, Materials Division, Glenn Research Center
- Paul Munafo, Manager, Materials, Processes, and Manufacturing Department, MSFC and as an alternate, Paul McConnaughey, Manager, Structures, Mechanics, and Thermal Department, Marshall Space Flight Center
- Charles Smith, Chief, Space Technology Division, Ames Research Center

8.0 Summary of Responsibilities

8.1 Specific Responsibilities of the NASA Langley Research Center

The Structures and Materials Competency Office at Langley Research Center is responsible for the following specific tasks:

1. Compile and publish an inventory of the Agency's structures and materials capabilities.
2. Coordinate the Center self-assessments, identify overarching themes, develop list of deficiencies, and benchmark NASA capabilities to those of outside organizations, as appropriate.
3. Lead the development of recommendations to address deficiencies, and proactively advocate appropriate implementation of the recommendations.
4. Coordinate the establishment of Working Groups, as needed.
5. Initiate a discussion with existing Working Groups that may be appropriate to facilitate the objectives of the SMSP.
6. Lead the development of the charter for new Working Groups, solicit names of the members from the interested Centers, and organize a kick-off meeting.
7. Coordinate the support for planning future programs as requests are received and opportunities identified.
8. Communicate throughout the SM Community the information regarding requests and opportunities to participate in planning activities.
9. Engage in regular (informational) discussions with key personnel in Enterprise and Program Offices.
10. Organize and participate in workshops of specific technical issues of interest to the SM Community.

11. Respond to requests for technical information using the Directory of Key Personnel as a source of referrals when the Office cannot fulfill a request.

12. Coordinate action items with appropriate Centers when requests to participate in urgent investigations of critical problems ("911 calls") are received.

13. Communicate throughout the SM community those requests for technical information or "911 calls" that involve multiple Centers.

14. Canvas the SM Community, compile, and distribute a list of existing structures and materials alliances.

15. Evaluate the list of alliances to identify needs not currently fulfilled by the existing alliances.

16. The SMSP will inform the SM Community of opportunities to form new alliances.

8.2 Summary of the Specific Responsibilities of each Center

Each Center in the SM Community is responsible for the following specific tasks:

1. Provide the data for the inventory of the Agency's structures and materials capabilities.

2. Conduct a periodic self-assessment of strengths, weaknesses, and gaps with respect to Enterprise goals and objectives.

3. Develop a Structures and Materials Facilities and Laboratories Brochure suitable for public dissemination.

4. Voluntarily participate in those Working Groups that directly benefit the participating Center.

5. Voluntarily participate in the planning activities as requests and opportunities arise.

6. Communicate throughout the SM Community the information regarding requests and opportunities to participate in planning activities.

7. Voluntarily participate in workshops of specific technical issues of interest to the SM Community.

8. Voluntarily participate in "911 calls" at a level judged to be appropriate by the Center(s) receiving the request from the SMSP.

9. Communicate throughout the SM Community those requests for technical information or "911 calls" that involve multiple Centers.

10. Provide a list of existing structures and materials alliances.

11. Identify opportunities for other community partners to join existing alliances.

12. Evaluate the list of alliances to identify needs not currently fulfilled by the existing alliances.

13. The specific actions to form new alliances will be the voluntary initiative of the individual members of the SM Community.

14. Appoint a member to serve on the SMSP Leadership Team. The Member will attend the annual Leadership Team Meeting to review the SMSP progress, prioritize recommendations, and provide guidance for the next year.

9.0 Agencywide Collaborative Activity Leads to Revolutionary New Technology

It is interesting to note that one of NASA's most significant and lasting technical contributions in the field of structures and materials was a direct result of a collaborative effort among all the NASA Field Centers. In January 1964, key personnel from all NASA Field Centers gathered at Headquarters in Washington to discuss efforts underway to improve structural analysis methods, particularly as it applied to the shell configurations commonly used in aerospace structure. Each representative described how his group had written special-purpose computer programs to analyze particular shell configurations. After this meeting, NASA Headquarters commissioned an ad hoc committee, with a representative from each NASA Center, to investigate the state of analysis methods in the aerospace industry. The first action taken by the committee was to visit the aircraft companies which were doing prominent work in developing computer-based advanced structural analysis methods. The committee's visits to the aircraft companies revealed that no single computer program incorporated enough of the best analysis features desired by NASA. Therefore, the committee recommended to Headquarters that NASA sponsor the development of its own computer program as a means to upgrade the analytical capability of the whole aerospace industry. Headquarters endorsed the recommendation and selected Goddard Space Flight Center (GSFC) to manage the development of the computer program. Under the leadership of GSFC, the ad hoc committee developed a visionary and thorough technical specification for the computer program and released a Request for Proposals in July of 1965. Much of the eventual success of the project was directly attributed to the initial work of the NASA committee in developing the thorough specification for the computer program. In December 1965, NASA awarded two Phase I contracts for preparation of a Technical Evaluation Report, one to a team led by the MacNeal-Schwendler Corporation (MSC) and one to the team led by Douglas Aircraft Company. After an evaluation of the two competing Phase I Reports and the associated Phase II proposals, MSC was selected as the recipient of the Phase II contract and began development of the computer program in July 1966. Shortly thereafter, NASA designated the name of the computer program to be the NASA STructural ANalysis (NASTRAN) Computer Program. The contracting team completed the computer program in 1969 and delivered it to all the NASA Field Centers. In February 1970, the Program Office at Goddard was disbanded. Later that year, NASA Headquarters established the NASTRAN Systems Management Office (NSMO) at Langley Research Center. The NSMO had the dual mission of maintaining NASTRAN and developing new capabilities for the program. A NASTRAN Advisory Group was set up to provide guidance to the NSMO. This Advisory Group consisted of members from each of the NASA Centers and was, in effect, a continuation of the ad hoc committee which drafted the initial NASTRAN specification in 1964. In November 1970, NASTRAN was released to the public through the COSMIC Distribution Center at the University of Georgia for the price of $1750. Less than a year later in September, the first NASTRAN Users Conference held at Langley Research Center was attended by about 200 representatives of the rapidly growing user community. Thus were the origins of the most successful finite element structural analysis computer code used throughout the world and in virtually all industrial sectors.

10.0 Concluding Remarks: Keys to Success

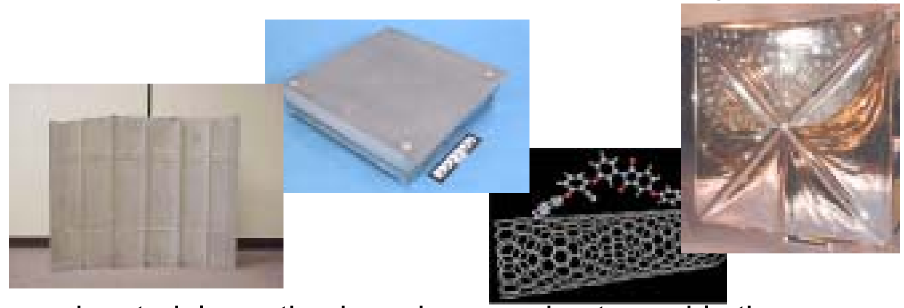
The implementation plan documented herein relies on three fundamental keys to success. These keys to success are building the SM community, a commitment of resources by the participating Centers, and developing high-payoff advanced technologies. First, the Structures and Materials SM Community is built on the voluntary partnership among 4 NASA Field Centers. Strategic alliances with external organizations will expand the Community. Collaborative activities among the Community partners will evolve from the thorough knowledge of the technical capabilities of each Community member. The SMSP communications network will foster collaboration. Second, the SM Community does not anticipate that the SMSP will be a source of funding to support research, technology development, or mission support. However, membership in the SM Community requires that each Center provide those resources necessary to implement the responsibilities listed in section 9.2 above. Third, it is incumbent upon the SM Community to identify and develop those high-payoff advanced technologies that enable future Agency missions. Each of these three “keys to success” are essential to achieving a meaningful fulfillment of the requirements set forth in this implementation plan.

NASA Structures & Materials

Strategic Partnership Plan

Appendix Capabilities

Langley Research Center



- **Technology Applications**
  - Aircraft primary structure
  - Primary structure, cryotank, and metallic TPS for space transportation vehicles
  - Advanced concepts for spacecraft
- **Technical Capabilities**
  - Research and technology development for advanced materials synthesis and processing to enable the fabrication of efficient, high-performance concepts for aerospace applications.
  - Research and technology development of efficient, physics-based analytical and computational methods to enable multidisciplinary design and analysis of advanced materials and structures for aerospace.
  - Research and technology development that evaluates concepts, quantifies behavior, durability, and damage tolerance, and validates performance of advanced materials and structures for aerospace applications.
  - Research and technology development for advanced nondestructive evaluation and health monitoring sensors as intelligent systems to ensure structural integrity, configuration control, reliability, and safety for aerospace applications.
  - Research and technology development to quantify and control impact dynamics, ground operations, and structural dynamics of aerospace systems.
  - Research and technology development to obtain a fundamental understanding and to quantify and control complex unsteady aerodynamics and aeroelastic phenomena experienced by aerospace vehicles.
  - Innovative structures and materials experimentation to identify unique phenomena, interrogate new theories, and quantify material and structural behavior using complex research facilities and equipment safely.
- **Facilities and Laboratories:**
  - Transonic Dynamics Wind Tunnel
  - Aircraft Landing Dynamics Facility
  - Structures and Materials Laboratory
  - Combined Loads Test Facility
  - Structural Dynamics Laboratory
  - Thermal Structures Laboratory
  - Fatigue and Fracture Laboratory
  - Polymer synthesis and composites fabrication laboratory
  - Carbon-carbon research laboratory
  - Light alloy synthesis, forming, and joining technology lab
  - Smart materials and superconductivity laboratory
  - Materials characterization and dimensional stability labs
  - Nondestructive evaluation sciences laboratory

Directory of Technical Points of Contact at LaRC

♦ SMSP Leadership Team:

– Mark J. Shuart	Director for Structures & Materials	757-864-3492

♦ Technical Points-of-Contact:

– Thomas E. Noll	Deputy Director	757-864-3492
– James J. Starnes, Jr.	Senior Engineer	757-864-3492
– Ivatory S. Raju	Senior Technologist	757-864-3492
– Joycelyn S. Harrison	Head, Advanced Materials and Processing Branch	757-864-4273
– Stanley R. Cole	Head, Aeroelasticity Branch	757-864-1207
– Jonathan R. Ransom	Head, Analytical and Computational Methods Branch	757-864-2907
– Damodar R. Ambur	Head, Mechanics and Durability Branch	757-864-3449
– Stephen J. Scotti	Head, Metals and Thermal Structures Branch	757-864-9393
– Edward R. Generazio	Head, Nondestructive Evaluation Scs. Branch	757-864-4970
– Howard M. Adelman	Head, Structural Dynamics Branch	757-864-2257
– Charles A. Poupard	Head, Applied Technologies and Testing Branch	757-864-3011

LaRC Facilities and Laboratories

- **Transonic Dynamics Wind Tunnel**
  - Only facility in the world capable of performing tests of scaled aeroelastic models at transonic speeds. Operating characteristics and use of heavy gas as a test medium unique in the world. Used in U.S. to clear aircraft for flutter.
- **Aircraft Landing Dynamics Facility**
  - Unique facility uses high pressure waterjet to accelerate a test carriage to maximum speeds of 220 knots for testing tires, braking systems, and runway surface treatments. Facility also includes a research laboratory with specialized test capability for the study of landing gear, tires, and runway friction. Most major airframers and tire manufacturers use test results to optimize ground performance.
- **Structures and Materials Laboratory**
  - Specially designed 120 Kip, 300 Kip, and 1,200 kip test machines for precision compression testing; high bay area with large platen for testing structural components
- **Combined Loads Test Facility**
  - Combined mechanical, pressure, and thermal loading capability that simulates subsonic and supersonic flight load conditions on transport wing and fuselage structures
- **Structural Dynamics Laboratory**
  - Three laboratories specifically designed for structural dynamics and pointing control research on aerospace structures and components.
- **Thermal Structures Laboratory**
  - Conducts a broad range of tests to characterize the behavior of advanced thermal structures subjected to combined thermal and mechanical loading conditions.
- **Fatigue and fracture laboratory**
  - Capability to characterize materials nonlinear stress-strain behavior; yield and ultimate strength of metals for uniaxial and biaxial stresses; fatigue life, fatigue crack growth, thermomechanical fatigue, and crack growth in ultra-high vacuum, inert gases, and salt water; fracture toughness; damage mechanisms and progressive failure of composites; elevated temperature creep, mechanical testing for combined tension/torsion, tension/bending, and in-plane biaxial loading condition.

LaRC Facilities and Laboratories, continued

- **Polymer synthesis and composites fabrication laboratory**
  - Synthesis and processing of novel polymers, adhesives, functional and smart polymers; computational materials, and polymer matrix composites; advanced composite fabrication including tape layup prepreg, powder coated towpreg, textile preforms and resin film infusion; and adhesives development and characterization.
- **Carbon-carbon research laboratory**
  - Complete processing capabilities for fabricating carbon-carbon composites and ceramic-composites, coatings deposition by chemical vapor deposition, pack cementation conversion, sol gel processing, graphitization and high-temperature heat treating to 2900 F, isothermal oxidation exposure testing of materials, mechanical property measurements, and ultra-high temperature materials exposure in high heat flux facility with black-body source to 6500K
- **Light alloy synthesis, forming, and joining technology laboratory**
  - Alloy synthesis, processing, and joining and comprehensive physical, chemical, and metallurgical analysis capabilities to develop advanced aluminum, aluminum-lithium, titanium, and metal matrix composites; facilities include metallography, optical microscopy, and electron optics for transmission, scanning, and microprobe analysis and crystallography; x-ray diffraction lab for phase identification, texture, and residual stress; synthesis and processing labs include vacuum hot press, hot isostatic press, plasma deposition, and physical and chemical vapor deposition.
- **Smart materials and superconductivity laboratory**
  - Ceramics and ceramic thin-film processing, piezoelectric materials development and characterization, piezoelectric actuator device development and performance testing, superconductivity materials development and characterization (current density vs. temperature, durability), class 100 clean room
- **Materials characterization and dimensional stability laboratories**
  - Capabilities include ultraviolet, visible, and infrared spectroscopy, outgassing measurements, mass spectrometers for analysis of volatile products from materials, glass transition temperature measurements, electron paramagnetic resonance spectroscopy for characterizing degradation mechanisms, specimen conditioning ovens, mechanical property measurements, cryogenic exposures, thermal expansion measurements with resolution to 0.5 ppm, and surface accuracy measurements on reflector panels.
- **Nondestructive evaluation sciences laboratory**
  - Advanced sensor technologies and signal processing software are being developed for ultrasonics, thermal, optical, electromagnetic, acoustic emission, x-ray radiography, computer aided tomography, and fiber optics with a fiber draw tower.

LaRC Capabilities: Research

Capabilities \ Applications	Aircraft		Space Transportation				Spacecraft		
	Airframe	Engine	Pri. Str.	Cryotank	TPS	Engine	Instru't	Structure	Power
Research: TRL 1-3									
polymer synthesis and processing	LARC		LARC	LARC			LARC	LARC	
PMC curing process dev	LARC		LARC	LARC			LARC	LARC	
PMC structure-property char.	LARC		LARC	LARC			LARC	LARC	
aluminum alloy synthesis & processing	LARC		LARC	LARC					
titanium alloy synthesis & processing	LARC		LARC	LARC					
metal forming and joining process dev	LARC		LARC	LARC	LARC				
metallic alloy structure-property char.	LARC		LARC	LARC	LARC				
refractory composite dev. & processing					LARC		LARC	LARC	
refractory composite struc-prop. char.					LARC		LARC	LARC	
mechanics of nonlinear material beh.	LARC		LARC	LARC				LARC	
mechanics of nonlinear structural beh.	LARC		LARC	LARC	LARC			LARC	
damage mechanisms and modeling	LARC		LARC	LARC	LARC		LARC	LARC	
fatigue and fracture mechanics methods	LARC		LARC	LARC					
damage tolerance struc. an. methods	LARC		LARC	LARC	LARC				
aeroelasticity computational methods	LARC		LARC						
struc. dynamics test & analysis methods	LARC		LARC	LARC			LARC	LARC	
sensor & measurement physics	LARC		LARC	LARC	LARC			LARC	
NDI system & signal processes algorithm	LARC		LARC	LARC	LARC				
smart/nano materials and structures	LARC						LARC	LARC	
radiation physics & transport code dev.	LARC		LARC					LARC	
radiation protection materials	LARC		LARC					LARC	
multidisciplinary optimization methods	LARC		LARC					LARC	
sonic fatigue models and pred. methods	LARC		LARC					LARC	
structural acoustic models	LARC		LARC					LARC	
textile preform PMC mat & str	LARC		LARC	LARC				LARC	
computational and design methodology	LARC		LARC	LARC	LARC			LARC	
structural analysis algorithms	LARC		LARC	LARC				LARC	
structural response and failure mechanisms	LARC		LARC	LARC				LARC	
NDE methods for mechanical prop char	LARC		LARC	LARC				LARC	
Active control of structural response	LARC		LARC					LARC	

LaRC Capabilities: Technology Development

Capabilities \ Applications	Aircraft		Space Transportation				Spacecraft		
	Airframe	Engine	Pri. Str.	Cryotank	TPS	Engine	Instru't	Structure	Power
Technology Development: TRL 4-6									
polymer & composite fabrication scale-up	LARC		LARC	LARC				LARC	
refractory composite fabrication scale-up					LARC			LARC	
metal forming process and fabr. scale-up	LARC		LARC	LARC	LARC				
durability, environmental effects, mis. sim.	LARC		LARC	LARC	LARC		LARC	LARC	
validation of structural concepts	LARC		LARC	LARC			LARC	LARC	
computational methods & design tools	LARC		LARC	LARC				LARC	
fatigue and fracture mechanics methods	LARC		LARC	LARC			LARC	LARC	
structural damage tolerance & durability met.	LARC		LARC	LARC					
structural concepts, dynamics, & design met.	LARC		LARC				LARC	LARC	
aeroelasticity	LARC		LARC						
NDI measurement systems & field demo	LARC		LARC				LARC		
in-situ health monitoring systems	LARC		LARC	LARC			LARC	LARC	
test methods for design allowables	LARC		LARC				LARC	LARC	
"subcomponent" design & manufacturing	LARC		LARC				LARC	LARC	
experimental methods & verification tests	LARC		LARC				LARC	LARC	
smart materials and structures	LARC		LARC				LARC	LARC	
multifunctional materials							LARC	LARC	
radiation protection materials	LARC		LARC				LARC	LARC	
vehicle / mission systems analysis	LARC		LARC					LARC	
thermal management	LARC		LARC		LARC		LARC	LARC	
multidisciplinary optimization applications	LARC		LARC					LARC	
control of sonic fatigue	LARC		LARC					LARC	
interior noise suppression	LARC		LARC					LARC	
NDE methods for mission assurance	LARC		LARC	LARC				LARC	
materials characterization	LARC		LARC	LARC				LARC	

LaRC Recent Technical Accomplishments

Advanced Polymer Matrix Composite Processing

- **Point of Contact: Joycelyn S. Harrison, Head, Advanced Materials and Processing Branch**
  - Low-cost, non-autoclave processes are critical to a number of NASA programs. Eliminating the dependence on autoclaves reduces cost and allows the production of extremely large composite structures without joints which add weight and create other complications. Advances were made two types of non-autoclave composite processing techniques. In support of the development of very large cryogenic tanks for RLVs in the NGLT program, a non-autoclave, double-vacuum bag process for high performance composites was developed. This method is an improvement over the standard single-vacuum-bag-only process where void formation as a result of volatile evolution during the cure cycle is difficult to eliminate. The second composite processing method developed is in the area of Vacuum Assisted Resin Transfer Molding (VARTM) where a process model was validated for non-tailored textile forms. Existing process models developed for RTM and resin film infusion (RFI) were not applicable due to the low pressures and flexible tooling associated with the VARTM process. A unique model coupling the perform compaction to the resin flow was developed. The new process model accurately predict resin flow front evolution, resin cure kinetics and preform compaction during the VARTM processing of non-tailored structures. These process models were not available previously and is expected to eliminate trial and error process development and part scrap rates. In addition, new high temperature resins (PETI-298) were synthesized to obtain Resin Transfer Moldable (RTM) laminates with excellent properties after 1000 hours at 288°C.

Aeroservoelastic Effects on the X-43A

- **Point of Contact: Stanley R. Cole, Head, Aeroelasticity Branch**
  - This research couples unsteady aerodynamics, structural dynamics, and controls into a unified aeroservoelastic (ASE) analysis of the X-43A Launch Vehicle (LV). This analysis was used to investigate the subsonic and transonic lateral dynamics of the vehicle during the boost phase. Strategies and techniques that incorporate nonlinear unsteady aerodynamics from CFD simulations into the aeroservoelastic analysis was also studied. These analyses were used to identify areas where aerodynamic nonlinearities may be influencing the lateral performance of the LV.
  - These analyses were performed in support of the NASA X-43A Mishap Investigation Board. The baseline linear ASE analysis verified the predicted gain margins assumed prior to the X-43A flight mishap. Post-flight analysis of the telemetry data indicated an increased effectiveness of the LV ailerons over that predicted prior to the flight. The nonlinear unsteady aerodynamics also predict an increased aileron effectiveness, and the resulting ASE analysis shows a decrease in the roll control gain margin that has been identified as a potential contributor to the X-43A mishap. The nonlinear aerodynamic analyses included in this research were performed only on the exposed fin of the vehicle, without the influence of other LV components like the fuselage or wing.

Collaborative Engineering Environment for Radiation Shielding Analysis

- **Point of Contact: Jonathan R. Ransom, Head, Analytical and Computational Methods Branch**
  - A collaborative Cave Automated Virtual Environment (CAVE) application that allows radiation calculations to be performed in 16A configuration of the International Space Station has been developed. Using this innovative application, the user can rearrange the equipment racks in the station to change its radiation shielding properties. The application also allows remote collaboration through network firewalls with users outside of the Center. This feature was developed and demonstrated in collaboration with the GRUVE Lab at the Glenn Research Center. During collaborative sessions, a remote participant was displayed in virtual environment as an avatar. In collaborative mode, either side can run calculations for analysis or change rack configurations while the other side observes, analyzes results, and suggests design modifications. This application allows engineers and scientists to now rapidly and accurately explore and understand radiation effects within spacecraft in a user-friendly virtual environment. In addition, this tool also enables remote collaboration over network allowing design engineers at different locations to collaborate on a given design to further allow development of future multidisciplinary design activity.

Methods for Prediction of Stiffened Panels

- **Point of Contact: Damodar R. Ambur, Head, Mechanics and Durability Branch**
  - A three-dimensional solid/shell element hybrid finite element method was developed to enable the failure prediction of a curved integrally stiffened panel. The analysis of the panel included both the pressure and axial loads subjected on the panel. Further, the analysis captured the nonlinear geometric response during the test. Finally, the analysis also captured the material anisotropy that is evident in any integrally machined structure. The impact of this task was development of a new computational capability that will be utilized to design an integral structure to replace riveted aircraft structure. The new design will be required to both reduce weight and improve damage tolerance. The first steps in this effort will involve material tailoring and investigating alternate means of structural assembly.

LaRC Recent Technical Accomplishments

Advanced Titanium Alloy Processing Development

♦ Point of Contact: Stephen J. Scotti, Head, Metals and Thermal Structures Branch

– Intermetallics based on the titanium-aluminum system, specifically gamma titanium aluminides, exhibit temperature-dependent properties comparable to nickel-base superalloys up to 1550°F (850 ° C), but possess approximately half the density. The objectives of this research were to use direct metal deposition processing for both the efficient production of sheet and foil and to produce materials exhibiting improved RT ductility without sacrificing other mechanical properties. The approach for this research is centered on the use of the low pressure, radio frequency (RF) plasma spray facility at NASA Langley Research Center (LaRC). The process involves injection of pre-alloyed powder feedstock into a plasma plume, causing powder melting, low-velocity impingement onto a rotating mandrel, and rapid solidification. The material is deposited on a sacrificial mild steel substrate, and the thickness is controlled by the deposition time. The resultant characteristics of the material produced include low impurity content (oxygen, hydrogen, nitrogen, and carbon) and a highly refined microstructure, both of which are known to enhance ductility. Following removal of the substrate, secondary processing to effect full density is achieved by applying a carefully controlled heating/loading cycle within a vacuum hot press. This task produced the first gamma titanium aluminide foil via RF plasma spray deposition and vacuum hot press consolidation. The characteristics of the material include a homogeneous, highly refined microstructure and a low-impurity content. The thickness of the final product can be controlled by selecting the number of as-sprayed plies used for consolidation. The scientific benefits revolve around the cleanliness of the process and the very-fine grain sizes attainable.

Utilization of Advanced Non-Destructive Evaluation Techniques

♦ Point of Contact: Edward R. Generazio, Head, Nondestructive Evaluation Scs. Branch

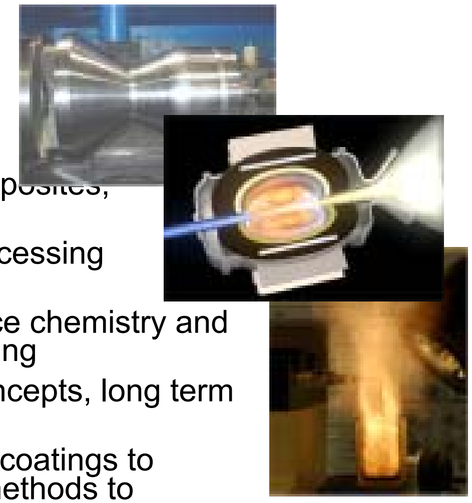
– The objective of this task was to assess the damage in the tail and rudder from the American Airlines 587 (AA587) accident. Mapping of the existing damage in a significant portion of the tail and rudder using the NDE techniques was accomplished by this task. Several different methods were used to determine the extent of damage on the tail and rudder. On the tail, an ultrasonic, thermographic, and Lamb wave technique were performed. Of particular importance is the ultrasonic method that determines the distance from the surface to a subsurface air gap, enabling the detection of delaminations in the tail. For the rudder, radiographic and thermographic techniques enable the mapping of trapped water in the honeycomb. A Lamb wave technique was used to characterize the effective stiffness of the face sheet, allowing mapping of regions where the face sheet had separated from the honeycomb. A report was sent to the National Transportation Safety Board and was included in the official record the for accident investigation. The results were also the basis of expert witness testimony at the National Transportation Safety Board public hearing on AA587 (October 29, 2002, through November 1, 2002).

LaRC Recent Technical Accomplishments

Large, In-Space Deployable Structures

- **Point of Contact: Howard M. Adelman, Head, Structural Dynamics Branch**
  - As the first step in developing a deployable modular large aperture structural system, a deployable strut fold was developed and implemented via a prototype folding machine. The design of the folded strut is based on origami and allows the ends of the folded strut to be attached to the necessary connecting joints. This will allow the development of a deployable (inflatable) modular structural system. This task is important because it is the first step towards a larger goal. It also is the basis of the next step in the development of a deployable modular large aperture structural system. This step will focus on rigidization of the deployable/inflatable strut.
  - In addition, a finite element method was developed for analysis of gossamer structures. Specifically, a non-linear dynamic finite element model of a hexapod gossamer structure was developed. The mode shapes as well as the test article's orientation for future controls and testing purposes was determined. In the future, the work of this task will extend the finite element model to incorporate the macro-fiber composite (MFC) actuators attached on the structure and will correlate the analytical results with experimental results.

Glenn Research Center



- ## Technology Applications
  - Propulsion Systems for aircraft engines and high temperature materials for space transportation vehicles
- ## Technical Capabilities
  - Development of superalloys, titanium, copper, and refractory metal alloys and composites, processing; and characterization
  - Development of functional ceramics and composites, fibers and fiber coatings, processing technologies, and characterization
  - Development of solid and liquid lubricants; thin film, wear resistant coatings; surface chemistry and topographical analysis; fiber-interface science; and computational materials modeling
  - Development of high temperature polymeric composites, advanced processing concepts, long term durability, and characterization
  - Development of protective high-temperature interface, overlay and thermal barrier coatings to enhance stability and durability in high velocity and pressure environments, and methods to assess, extend and predict life and durability
  - Computational and experimental methods to assure life, durability, and integrity of high temperature aeropropulsion and power systems
  - Structural concepts and design/optimization tools; aeromechanical response of fans, compressors, and turbines; and active/passive vibration and instability control
  - Computational and experimental acoustics and aerodynamics for reducing fan, propeller, jet, and core noise
  - Aeropropulsion mechanical component technologies including transmissions, gears, bearings, seals, health monitoring and lubrication
- ## Facilities and Laboratories
  - Polymeric materials processing and testing laboratory
  - Metallic materials processing and testing laboratory
  - Ceramic materials processing and testing laboratory
  - Structural mechanics laboratories
  - Environmental durability laboratories
  - Life prediction complex (fatigue and fracture laboratory)
  - Space environmental durability evaluation laboratory
  - Martian atmosphere chemistry simulation facility
  - Propulsion structural dynamics laboratories
  - Magnetic suspensions laboratories
  - Propulsion component NDE laboratories
  - Propulsion mechanical components laboratories
  - Tribology facilities
  - Materials characterization and analysis laboratories
  - Aeroacoustic wind tunnels and component test rigs
  - Vibration test laboratory
  - Structural static lest laboratory

Directory of Technical Points of Contact at GRC

- **SMSP Leadership Team:**

– Hugh R. Gray	Chief, Materials Division	216-433-3230

- **Technical Points-of-Contact:**

– Michael V. Nathal	Chief, Advanced Metallics Branch	216-433-9516
– Ajay K. Misra	Chief, Ceramics Branch	216-433-8193
– Michael A. Meador	Chief, Polymers Branch	216-433-9518
– Leslie Greenbauer-Seng	Chief, Environmental Durability Branch	216-433-6781
– John P. Gyekeneysi	Chief, Life Prediction Branch	216-433-3210
– George L. Stefko	Chief, Structural Mechanics and Dynamics Branch	216-433-3920
– Dennis L. Huff	Chief, Acoustics Branch	216-433-3913
– James J. Zakrajsek	Chief, Mechanical Systems Branch	216-433-3968
– Phillip B. Abel	Chief, Tribology and Surface Science Branch	216-433-6063
– George Y. Baaklini	Chief, Optical Instrumentation Technology Branch	216-433-6016
– Richard T. Manella	Chief, Structural Systems Dynamics Branch	216-433-2590
– Mei-Hwa Liao	Chief, Structural Analysis Branch	216-433-3787
– Bruce A. Banks	Chief, Electro-Physics Branch	216-433-2308

GRC Facilities and Laboratories

- **Polymeric materials processing and testing laboratories**
  - Fabrication and processing of lab-scale polymeric and composite samples, prepregging, autoclave processing, hot pressing and vacuum hot pressing, instrumented impact tester, elevated temperature tensile testing to 700 F, autoclave and long-term aging/durability rigs.
- **Metallic materials processing and testing laboratories**
  - Complete metals, alloys and metallic composites processing facilities including melting/casting, powders, hot working, and welding and joining. Sixty-five (65) creep test machines, 10 universal testing machines, 6 thermomechanical fatigue rigs, elevated temperature capability to 5400 F with controlled atmospheres and vacuum.
- **Ceramic materials processing and testing laboratories**
  - Processing facilities for green-article fabrication, tape casting, hot pressing and hot-isostatic pressing; single crystal fiber growth facility, inert and air tensile testing to 3000 F in fast fracture and creep modes.
- **Structural mechanics laboratories**
  - Smart propulsion structures lab for vibration mitigation and aero-acoustic emission suppression, ballistic blade impact/containment structures lab, computational propulsion structures evaluation and optimization lab.
- **Environmental durability laboratories**
  - Burner rigs and cyclic oxidation, ambient and low pressure plasma spray facilities, and high temperature mass spectrometer laboratory; high heat flux/thermal fatigue laser test lab, high heat flux rocket materials facility.
- **Life prediction complex (fatigue and fracture laboratory)**
  - 48 fatigue test machines for low cycle fatigue, high cycle fatigue, and thermomechanical fatigue, mechanical load capability to 110 Kips, and subcomponent test rigs, fiber-matrix interface testing and evaluation.

GRC Facilities and Laboratories, continued

- **Propulsion structural dynamics laboratories**
  - Bladed stage mechanics spin rig, rotor dynamics vibration suppression lab, rotor vibration control dampers, shaft dampers, blade damping facilities, turbine stage aeroelastic flutter and forced vibration facilities.
- **Magnetic suspensions laboratories**
  - Multi-planar elastic mounted turbomachine high speed magnetic bearings lab for extreme temperature service, magnetic levitation lab, real-time controls and electromagnetic actuators lab.
- **Propulsion component NDE laboratories**
  - Ultrasonic, computed tomography, radiologic NDE lab for high temperature, ceramic, refractory alloy, high temperature composite propulsion materials and components.
- **Propulsion mechanical components laboratories**
  - Structural panel and engine flow path seals, rolling element components, bearings, geared systems, mechanical system noise generation and emission control, health monitoring, and environmental simulation rigs for thermal extremes, vacuum, Lunar and Martian soil simulation.
- **Tribology facilities**
  - Foil bearing and brush seal rigs, high temperature and vacuum tribometer test facilities, and surface analysis laboratory
- **Materials characterization and analysis laboratories**
  - Chemistry labs, metallography labs, and nondestructive evaluation labs; nuclear magnetic resonance facility including imaging and high temperature (500 F) solids capabilities; surface topography lab
- **Aeroacoustic wind tunnels and component test rigs**
  - 9’x15’ Low-Speed Wind Tunnel, Aeroacoustic Propulsion Laboratory which houses the Nozzle Acoustic Test Rig (NATR), the Active Noise Control Fan (ANCF), and the Small Hot Jet Acoustic Rig (SHJAR).

GRC Facilities and Laboratories, continued

- **Space environmental durability evaluation laboratory**
  - World's largest capacity atomic oxygen beam facility and the only one with in-vacuum spectral reflectance characterization; large area 5'x7' atomic oxygen exposure facility, high rate thermal cycling facilities, soft x-ray exposure facility, 13 atomic protective coatings evaluation facilities, and protective coatings deposition facilities.
- **Martian atmosphere chemistry simulation facility**
  - Capable of simulating the pressure, gas composition, and temperatures of expected space systems operating on the surface of Mars.
- **Vibration test laboratory**
  - 40K, 28K, and 6K-lbf shakers for qualification testing of flight hardware.
- **Structural static lest laboratory**
  - Multi-axial strength characterization of flight hardware, stiffness characterization and life tests of structures, proof tests of pressure vessels, and component testing of engineering materials.

GRC Capabilities: Research

Capabilities \ Applications	Aircraft		Space Transportation				Spacecraft		
	Airframe	Engine	Pri. Str.	Cryotank	TPS	Engine	Instru't	Structure	Power
Research: TRL 1-3									
Sensory / adaptive structures		GRC				GRC			GRC
Impact mechanics/containment concepts		GRC							
Simulation / probabilistic design methods		GRC				GRC			GRC
Brittle material/composites life models		GRC				GRC			GRC
High Temp deformation/fatigue physics		GRC				GRC			GRC
High Temp materials character/testing		GRC				GRC			GRC
Propulsion system flutter		GRC				GRC			
Aero forced vibration		GRC				GRC			
Propulsion system rotor/comp dynamics		GRC				GRC			
Active/passive vibration control		GRC				GRC			
Turbomachinery noise reduction		GRC				GRC			
Jet and fan noise modeling		GRC							
Materials / lubricants for mechanical power transfer		GRC				GRC			
Mechanics / physics of rotating machinery elements		GRC				GRC			
Adv. 700 F resin chemistry		GRC				GRC			
High temp Titanium and superalloy dev.		GRC				GRC			GRC
High temp met. alloy and composites dev.		GRC				GRC			GRC
Long life durable, Hi Temp coatings		GRC				GRC			GRC
Low cost processing/process dev.		GRC				GRC			GRC
Long time aging / durability of materials		GRC				GRC			GRC
Material degradation mechanisms, life prediction and protection schemes		GRC				GRC			GRC
Fiber/matrix interactions/coatings		GRC				GRC			GRC
Advanced fibers and ceramic composites		GRC			GRC	GRC			GRC
Tribological coatings		GRC				GRC			GRC
Hi Temp computational Mat'l science		GRC				GRC			GRC
Hi Conductivity copper alloys / comps.		GRC				GRC			GRC
Toughened ceramics		GRC				GRC			GRC
Nanotechnology (C, SiC and Boron Nitride)		GRC				GRC			GRC

GRC Capabilities: Technology Development

Capabilities \ Applications	Aircraft		Space Transportation				Spacecraft		
	Airframe	Engine	Pri. Str.	Cryotank	TPS	Engine	Instru't	Structure	Power
Technology Development: TRL 4-6									
Sensory / adaptive engine structures		GRC				GRC			
Containment structures		GRC							
Structure design / optimization tools		GRC				GRC			GRC
Brittle structure / component design tools		GRC				GRC			GRC
Hi Temp complex coupon / component lifing		GRC				GRC			GRC
System flutter & aero forced vibration		GRC				GRC			
System rotor & component dynamics		GRC				GRC			
System active / passive vibration control		GRC				GRC			
Turbomachine noise reduction		GRC				GRC			
Jet and fan noise reduction / active noise control		GRC							
Mechanical power transfer components		GRC				GRC			
Mechanical power transfer health monitoring		GRC				GRC			
PMC Propulsion materials development		GRC							
Metallic fan / compressor mat'ls devel.		GRC				GRC			
Radiator/hi heat transfer mat'ls devel.		GRC				GRC			GRC
Combustor materials devel/eval.		GRC				GRC			GRC
Turbine blade / disk alloys/composites		GRC				GRC			
Titanium / superalloys and composites for high temp. components		GRC				GRC			GRC
Hi velocity, long term durability materials eval./life modeling		GRC				GRC			
Long life, durable protective coatings		GRC				GRC			GRC
Solid / liquid lubes		GRC				GRC			GRC
Low cost mat'l processing scale-up concepts		GRC				GRC			GRC
"Green" polymer mat'ls / processes		GRC				GRC			
Thin film tribological coating/process		GRC				GRC			GRC
Ceramics/Cer Comp. for high temp appl		GRC			GRC	GRC			GRC

GRC Recent Technical Accomplishments

Advanced Metallics

- **Point of Contact: Michael V. Nathal, Chief, Advanced Metallics Branch**
  - The Advanced Metallics Branch has developed GRCop-84, a new, high temperature copper alloy that far exceeds the capabilities of today's alloys for use in future space vehicles. Rocket engine combustion chamber liners have been a major limiting factor for the life and performance of the space shuttle main engine (SSME). Use of GRCop-84 will achieve an estimated 50% reduction in manufacturing cost, 50% reduction in delivery time, plus additional operational cost savings through an anticipated 2X-50X improvement in life (number of missions). Simultaneously with life improvement, GRCop-84's improved strength (2X) and temperature capability (+350°F) over today's alloys will provide improvements in rocket performance. The benefits of lower cost and increased life and safety from GRCop-84's use can be applied to both existing and future combustion chamber designs. The new alloy and supporting technologies have been developed to the point that all three major rocket engine manufacturers have active programs pursuing the introduction of GRCop-84 into their product line.

Ceramics

- **Point of Contact: Ajay K. Misra, Chief, Ceramics Branch**
  - The Ceramics Branch research has resulted in significant advances in many technologies. In the area of ceramic matrix composites (CMCs), researchers have successfully developed a silicon carbide fiber reinforced silicon carbide (SiC/SiC) CMC material with 2400oF temperature capability for gas turbine engine applications. This material is the best CMC available today and has been successfully tested in full scale combustor test at GE Aircraft Engines. An earlier version of this material, with 2200oF temperature capability, has successfully completed > 10,000 hr of testing in ground power generation engine tests by Solar Turbine. Several cooled CMC heat exchanger concepts have been successfully tested in GRC's Research Combustion Laboratory. Robust joining techniques have been developed to join SiC/SiC CMC to other ceramics and metals. In the area of monolithic silicon nitride, an innovative process that combines gel casting and ink jet printing has been developed to fabricate internally cooled silicon nitride vanes for small gas turbine engines. Boron nitride nanotubes have been successfully grown in the laboratory using a reactive ball milling process, with a yield of several grams per day. Boron nitride nanotubes are more oxidation resistant than carbon nanotubes, and will be used as reinforcements for ceramic composites. Piezoceramic materials with high temperature capability are being developed for application as smart components in gas turbine engines. Single crystals of lanthanum titanate, a high piezoceramic material, have been successfully produced using laser float zone technique.

GRC Recent Technical Accomplishments

Polymers

- **Point of Contact: Michael A. Meador, Chief, Polymers Branch**
  - GRC Polymers research has led to significant advances in the development of polymeric materials for aerospace power and propulsion applications. A new high temperature polyimide, HFPE, has been developed with outstanding retention of mechanical properties at temperatures up to 343°C. Improvements in the stability and mechanical properties of high temperature polymers and fiber reinforced composites have been achieved through the addition of small amounts of organically modified clays. Addition of 1 weight percent of these clays to a carbon fabric reinforced PMR-15 composite, leads to a 50% reduction in oxidative weight loss (1000 hours at 290°C) and a 30% increase in flexural strength (room and 290°C). Other nanocomposites have been developed for lightweight cryogen storage applications with 100-fold lower hydrogen than the base resin. Purification techniques have been developed for single wall carbon nanotubes which reduce their iron content from 22.7 to 0.03 weight percent and increase their stability by 300°C. Functionalization chemistries have been developed that enable the homogeneous dispersion of nanotubes in a polymer matrix. Erosion resistant coatings have been developed and engine tested on stator vanes which double the lifetime of these components and significantly reduce maintenance costs and maintenance related down-time. New polymer electrolytes have been developed for use in lithium-polymer batteries with room temperature lithium ion conductivity ten times that of the state of the art electrolyte material.

Environmental Durability

- **Point-of-Contact: Leslie A. Greenbauer-Seng (Chief, Environmental Durability Branch)**
  - The Environmental Durability Branch research staff has made important contributions to the development, evaluation and application of advanced metallic, ceramic, polymer and composite materials for application in propulsion and power systems. Studies of the severity of many material durability issues, such as oxidation, volatility, recession, compatibility, diffusion, corrosion and erosion/wear studied have necessitated development of protection schemes. Recent accomplishments include: Development of a HfO_2-based coatings and demonstration of the coating feasibility on SiC/SiC systems to enable 3000°F capable CMCs; Development of a low conductivity, highly stable, durable zirconia-based thermal barrier coating capable of accommodating more severe thermal gradients and therefore higher surface temperatures, yet maintaining excellent durability (2002 TIGR Award); Development of environmental barrier coatings demonstrating protection of SiC/SiC composites to 2700oF in simulated combustion environments (R&D 100 and 2001 TIGR Award for first generation, lower temperature coating), and; Identification of new coatings which have shown improved oxidation resistance protection for Cu-alloys being developed for space propulsion combustor applications. Development of new rod-coil block co-polymers, for application as solid electrolytes in lithium polymer batteries, have shown that the highest molecular weight polymers with the largest degree of branching have produced films with higher conductivity and durability. Critically important studies of the Space Shuttle wing reinforced carbon/carbon (RCC) leading edges have been completed and include a study to identify (sodium carbonate) and assess the impact of deposits first found on the on Shuttle wings in 2001, and more recently, Columbia accident investigation studies of the chemistry and microstructural nature of deposits found on recovered RCC debris.

GRC Recent Technical Accomplishments

Life Prediction

- **Point-of-Contact: John P. Gyekeneysi, Chief, Life Prediction Branch**
  - The Life Prediction Branch has developed a series of state-of-the art design/analysis software codes that enable the use advanced Ceramic Matrix Composite materials in space and aero propulsion components such as combustor liners and turbine vanes. The codes CEMCAN, WCEMCAN, PCEMCAN and PCGINA include probabilistic material behavior models that enable the reliable, efficient analysis of composite materials. The life prediction branch also developed methodologies and codes such a CODSTRAN for assessing the durability and damage state of composite structures via progressive fracture analysis. Participants in this software development included NASA Langley and the University of Clarkson. The code can be used for performing progressive, damage based durability and life analysis of ceramic and polymer matrix composite structures, as well as monolithic structures. Work also continues in fatigue testing and analysis for materials subjected to harsh, high temperature environments in support of aerospace applications.

Structural Mechanics and Dynamics

- **Point-of-Contact: George L. Stefko, Chief, Structural Mechanics and Dynamics Branch**
  - The Structural Mechanics and Dynamics Branch has established a comprehensive research programs in the following four areas: 1.) Propulsion Aeroelasticity 2.) Magnetic Rotor Suspension, 3.) Ballistic Impact and 4.) Probabilistic Structural Analysis. One recent accomplishment in the Propulsion Aeroelasticity area was the development and delivery of a 3D viscous CFD/aeroelastic code called TURBO-AE to Honeywell, GE, Williams International, Siemans Westinghouse, the Air Force, Navy, Army, and ten universities. This code has been shown to accurately predict turbomachinery aeroelastic flutter and forced response problems. A high temperature magnetic bearing has also been developed which contains a modular C-core stator construction, optimized rotor/lamination assembly, high temperature wire, stator mounting to accommodate radial and axial thermal expansion while maintaining structural integrity under load and new coil winding & core manufacturing approaches (three patents pending). This bearing has a nominal load capacity of 1000 lb force and has been demonstrated to operate fault tolerant at 1000°F to 25,000 rpm or 1.9MDN. Another recent accomplishment by the Ballistic Impact team was test support and analysis for foam impact experiments at both GRC and Southwest Research Center to help the Columbia accident investigation team.

GRC Recent Technical Accomplishments

Acoustics

- **Point-of-Contact: Dennis L. Huff, Chief, Acoustics Branch**
  - The Acoustics Branch has focused on aeroacoustics technology and noise reduction methods for air-breathing propulsion systems. Most of the research is for turbofan engines for subsonic and supersonic aircraft applications. Over the past five years, new acoustic measurement methods have been applied for fan and jet noise source identification, such as phased microphone arrays and Particle Image Velocimetry (PIV). Dedicated source diagnostics tests have been performed that separate fan noise sources and help guide the direction of future research. Computational AeroAcoustics (CAA) codes have been developed for fan and jet noise prediction. Significant progress has been made using active noise control to reduce fan tones for inlet and aft radiated noise. Engine validation tests have been done on the PW4098 and TFE731-60 engines. Chevron nozzles, variable area nozzles, advanced acoustic liners, and swept/leaned stators have been validated in static engine tests and flight tests. Over the past three years, the branch has supported the Quiet Aircraft Technology Program in close coordination with NASA Langley. Significant progress has been made toward achieving NASA's 10 dB aircraft noise reduction goal in 2007.

Mechanical Systems

- **Point-of-Contact: James J. Zakrajsek, Chief, Mechanical Components Branch**
  - The Mechanical Components Branch has developed advanced thermal barrier seal technologies critical for the successful operation of current and future space launch vehicles. Researchers in the Mechanical Components Branch developed a new patented seal technology that uses braided carbon fibers to provide reliable and robust thermal protection from high temperature combustion gases in solid rocket nozzle joints. The new seal technology will be used in the re-designed nozzle-to-case joint of the Space Shuttle Solid Rocket Motor. Recently, the final certification test firing of a full scale Space Shuttle Solid Rocket Motor with the new nozzle joint design was successfully completed. Even with an intentional flaw, the new thermal barrier seal successfully blocked 5500 F combustion gasses from damaging critical viton o-rings in the joint. This new patented thermal barrier seal technology was also applied successfully to the critical nozzle-to-case joint of the new solid rocket motors of the Atlas V launch vehicle. The new thermal barrier seal technology was part of an extensive joint re-design that was required after a catastrophic ground test failure of the new motor due to hot gas penetration of the joint. The new Atlas V launch vehicle, incorporating thermal barrier technology developed at GRC, was successfully launched on July 17, 2003. Researchers in the Mechanical Components Branch are currently working on developing advanced thermal barrier seal technologies and unique test facilities to meet the even more challenging requirements of future launch vehicles.

GRC Recent Technical Accomplishments

Tribology and Surface Science

- **Point-of-Contact: Phillip B. Abel, Chief, Tribology and Surface Science Branch**
  - Building upon decades of fundamental tribology research into novel solid and liquid lubricants for extreme conditions, the Tribology and Surface Science Branch has continued to generate multiple award winning aerospace and "spin-off" applications. Basic research into the tailorable properties of plasma sprayed composite tribological coatings (PS300 series) led to commercial licensing/availability of the NASA patented formulation/process, and use of the coatings in extreme applications such as commercial power plant steam valves and in a commercially available Oil-Free gas turbine generator. A powder metallurgy solid version of the composite coating material (PM300) sold in the form of bushings is proving to be a money saving replacement for traditional self-lubricating parts in industrial furnaces. Applied to foil air bearings and in combination with computational modeling, these tribological coatings are enabling the Oil-Free Turbine Engine Technology (OFTET) project continued progress, as demonstrated by successful completion of the Oil-Free engine "Core Hot Bearing Tests" Level I project milestone. Recently accomplished world-unique Oil-Free bearing test facilities/research capabilities have enabled further maturation of the technologies needed for an oil-free engine.

Nondestructive Evaluation

- **Point-of-Contact: George Y. Baaklini, Chief, Optical Instrumentation Technology Branch**
  - Over the past five years, the nondestructive evaluation (NDE) group has grown its technical portfolio by newly developing advanced acoustics, thermal, real time radiography, and has established a major research and technology activity in the area of health monitoring and engine diagnostics. Also NDE-based flywheel certification approaches were established for potential energy storage applications on the space station. The group has expanded acousto-ultrasonic technology to second generation guided wave scanning system for advanced and more accurate material characterization of polymer and ceramic matrix composites. NDE capacitive sensors and methods were developed and integrated around dual bearing rotor dynamic spin systems for disk crack detection and damage degradation assessment. The goals are to assess accumulated damage and improve the understanding of material residual life and residual mechanical/thermal properties, to incorporate and validate life prediction and modal norms models, and to provide critical NDE sensors/parameters that can help identify the global and local states of remaining life. Substantial progress in nonlinear acoustics and thermal acoustics were realized for the characterization of Ni- and Ti-based engine components. Wireless Eddy current for on wing engine health monitoring was also demonstrated at the macro level. Continued refinement and miniaturization with IC technology, multiple probe types, and programmable frequency are being pursued.

Ames Research Center

- **Technology Applications**
  - Thermal protection systems (TPS)
  - Advanced TPS materials and systems concepts
  - Advanced TPS Analysis Capabilities
  - Unique TPS Test Facilities
- **Technical Capabilities**
  - Development of reusable and ablative TPS materials and systems including characterization, test, and instrumentation
  - Arc Jet and Flight Testing of TPS
  - Development of tools to model TPS interactions with shock layer gases and radiation, and to define TPS designs to meet specific mission requirements
- **Facilities and Laboratories**
  - Aerodynamic heating facility
  - Interactive heating facility
  - Panel test facility
  - 2x9 turbulent flow duct
  - Giant planet facility
  - Thermal blanket acoustic re-entry simulator
  - Ames vertical gun range
  - Ames Hypervelocity Free-Flight Aerothermodynamic Facility
  - Ceramic TPS processing laboratory
  - Organo-ceramic TPS processing laboratory
  - Flexible TPS processing laboratory
  - Laser accurate surface catalysis laboratory
  - Thermal, mechanical, and analytical materials characterization laboratories

Directory of Technical Points of Contact at ARC

- **SMSP Leadership Team:**

– Charles Smith	Chief (acting), Space Technology Division	650-604-5857

- **Technical Points-of-Contact:**

– Charles Smith	Deputy Chief, Space Technology Division	650-604-5857
– Sylvia M. Johnson	Chief, Thermal Protection Materials and Sys. Br.	650-604-2646
– Dean A. Kontinos	Chief, Reacting Flow Environments Branch	650-604-4283
– G. Joseph Hartman	Chief, Thermo-Physics Facilities Branch	650-604-5269

ARC Facilities and Laboratories

- **Aerodynamic Heating Facility**
  - Convective stagnation-point heat flux applied to nose cap or wedge-shaped test bodies in conical nozzle flow streams from 12 to 36 inches in diameter. The 8-foot test chamber is evacuated by 5-stage steam ejector pump and has optical access. Air, nitrogen, or argon is heated by a 20 MW electric arc heater with enthalpy ranging from 2000 to 15,000 Btu/lb operating up to 30 minutes.
- **Interaction Heating Facility**
  - Two facility configurations: Convective heat flux is applied to 32 x 32 inch panels at variable angle of attack obtaining surface temperatures from 800 to 2700F with small pressure and temperature gradients; or convective stagnation-point heat flux applied to nose cap or wedge-shaped test bodies in conical nozzle flow streams from 6 to 41 inches in diameter. The 8-foot test chamber is evacuated by 5-stage steam ejector pump and has optical access. Air is heated by a 60 MW electric arc heater with enthalpy ranging from 2000 to 20,000 Btu/lb operating up to 30 minutes. Three dimensional test articles can be run in the panel test mode and run-time optical access is possible.
- **Panel Test Facility**
  - Convective heat flux from transition/turbulent supersonic flow is applied to 16 x 16 inch panels at variable angle of attack obtaining surface temperatures from 800 to 2700 F with small pressure and temperature gradients. The 4-foot test chamber is evacuated by 5-stage steam ejector pump and has optical access. Air is heated by a 20 MW electric arc heater with enthalpy from 2000 to 15,000 Btu/lb operating up to 30 minutes. Three dimensional test articles can be run in the facility and run-time optical access is possible.
- **2x9 Turbulent Flow Duct**
  - Convective heat flux from highly turbulent supersonic flow is applied to 8 x 20 inch panels within an enclosed duct obtaining surface temperatures from 1000 to 3000 F with small gradients in pressure and temperature. The 2 x 9 inch cross section duct is evacuated by 5-stage steam ejector pump and has optical access. Air or nitrogen is heated by a 15 MW electric arc heater at enthalpy levels from 2000 to 5,000 Btu/lb for up to 30 minutes.

ARC Facilities and Laboratories, continued

- **Giant Planet Facility**
  - Combined convective and radiative stagnation-point heat flux applied to 1.5 inch diameter blunt test bodies in a supersonic hydrogen plasma in a conical nozzle of diameter 2.75 inches. The 8-foot test chamber can exhaust to atmosphere or the 5-stage steam ejector vacuum pump and has optical access. Hydrogen gas mixtures are heated by an 80 MW electric arc heater with enthalpy ranging from 150,000 to 300,000 Btu/lb operating up to several minutes. Facility is on standby (9/97).
- **Thermal Blanket Acoustic Re-Entry Simulator**
  - Acoustic testing of a 4 x 4 inch panel in a room-temperature supersonic flow duct in a 4-foot evacuated test chamber with optical access. Acoustic levels to 165 dB with dynamic pressure to 510 psf.
- **Ames Vertical Gun Range**
  - Impact physics
- **Ceramic TPS processing laboratory**
  - Facilities for fabricating fibrous ceramic TPS materials and components. An example product from this facility is a new durable tile, TUFI (Toughened Uni-piece Fibrous Insulation), which is replacing damaged original tiles on all the Shuttles to reduce operational costs.
- **TPS Development laboratory**
  - Facilities for fabricating ceramic TPS from organo-ceramic materials and components. Example products from this facility include SIRCA and PICA ablative materials being used in planetary missions. Other examples include TUFROC and ROCCI being fabricated as potential materials for the X-37 heat shield, and durable ceramic foams being developed for new acreage materials.
- **Ames Hypervelocity Free-Flight Aerothermodynamic Facility**
  - Models are launched from the 1.5 inch diameter light-gas gun to fly at hypervelocity through the 100 ft long test section. This facility allows aerothermodynamic testing of actual nosetip / heatshield materials in flight environments that simulate a reentry trajectory point in Earth's atmosphere, or in non-terrestrial atmospheres. Such tests can be utilized to define the relative transition-to-turbulence performance of various TPS materials in quiescent real-gas environments. Measurements of transition location and global surface temperature distributions are obtained optically using high-speed visible and infrared imaging cameras.

ARC Facilities and Laboratories, continued

- **Flexible TPS design capability**
  - Design and development capability for flexible TPS materials and components. An example product from this facility is DurAFRSI, a metallic foil-faced flexible blanket being developed for use as a flight experiment for the X-37.
- **Laser accurate surface catalysis laboratory**
  - Facilities and laser diagnostics for measuring chemical surface recombination characteristics of materials. This facility is being used to determine the catalytic and optical properties of the coated metallic TPS for the X-37
- **Thermal, mechanical, and analytical materials characterization laboratories**
  - Facilities for measuring conductance, specific heat, mass and composition stability, and flow permeability characteristics of fibrous materials; optical properties of TPS materials and coatings; moduli, strengths and impact capabilities of fibrous materials; and facilities for performing sectioning and polishing, optical microscopy, electron microscopy, and elemental and crystalline structural analyses of materials
- **Cryogenics Laboratory**
  - Facilities for measuring thermal contact conductance at cryogenic temperatures, thermal conductivity and moisture adsorption of insulating materials from 20 K to 300 K. Pulse tube cryocooler development facility for development, fabrication, and testing of complete pulse tubes as well as regenerators. Dilution and Adiabatic Demagnetization Refrigerator (ADR) development capability.

ARC Capabilities: Research

Capabilities \ Applications	Aircraft		Space Transportation				Spacecraft		
	Airframe	Engine	Pri. Str.	Cryotank	TPS	Engine	Instru't	Structure	Power
Research: TRL 1-3									
Low cost internal multilayer insulation dev					ARC				
Organic composite TPS materials dev					ARC				
Ultra High Temp. Ceramic TPS Dev					ARC				
Erosion resistant TPS dev					ARC				
High temperature felt TPS dev					ARC			ARC	
Flexible blanket advancements					ARC				
Coatings development					ARC				
Attachment technologies dev					ARC			ARC	
Waterproofing development					ARC				
Material surface characterization					ARC			ARC	
TPS sensors and instrumentation					ARC			ARC	
TPS vehicle health management dev					ARC		ARC	ARC	
Smart TPS materials					ARC		ARC		
Low cost TPS concept dev					ARC			ARC	
TPS seal, gap, and joint development					ARC			ARC	
Arc Jet Flow Characterization					ARC				
Analytical Models of TPS performance					ARC			ARC	
Densified Propellant Cryogen Storage				ARC					

ARC Capabilities: Technology Development

Applications / Capabilities	Aircraft		Space Transportation				Spacecraft		
	Airframe	**Engine**	**Pri. Str.**	**Cryotank**	**TPS**	**Engine**	**Instru't**	**Structure**	**Power**
Technology Development:TRL 4-6									
Refractory Diboride ceramics TPS					ARC				
Advanced Ablators dev					ARC			ARC	
Toughened ceramic TPS dev					ARC				
Metallic covered flexible blanket dev					ARC				
High fidelity TPS sizing tool development					ARC			ARC	
Integrated Design Systems					ARC			ARC	
TPS Operability Analysis tool development					ARC			ARC	
Arc Jet & Aerothermal testing					ARC			ARC	
Low Cost TPS development					ARC				
Ceramic TPS manufacturing Methods					ARC			ARC	
Coolers for Zero Boil Off Cryogen Storage				ARC					

ARC Recent Technical Accomplishments

Planetary entry missions use Ames Lightweight Ablators and TPS sizing tools

- **Point-of-Contact: Sylvia M. Johnson, Chief, Thermal Protection Materials and Systems Branch**
  - A number of recent planetary entry missions are using Ames-invented and patented lightweight ceramic ablators. Silicone Impregnated Reusable Ceramic Ablator (SIRCA) is the backshell heatshield of the entry probes for Mars Pathfinder and the Mars Explorer Rovers. Phenolic Impregnated Carbon Ablator (PICA) is the forebody heatshield of the Stardust Sample Return Capsule. TPS sizing tools developed by Ames were used to design heatshields for the Mars Pathfinder, Stardust, and Mars 2001 Aerocapture and Lander vehicles.

TPS Development Tasks for the X-37 Flight Project

- **Point-of-Contact: Sylvia M. Johnson, Chief, Thermal Protection Materials and Systems Branch**
  - Ames Research Center is performing Wing Leading Edge Material Development and Production and System Design Evaluation for the X-37 Program. This task includes performing Thermomechanical Stress Modelling, TPS Material Optimization, and TPS Material Characterization, including mechanical property determination, surface characterization, and material response to simulated reentry environments.

Ames successfully demonstrates United States leadership in ultra-high temperature TPS materials

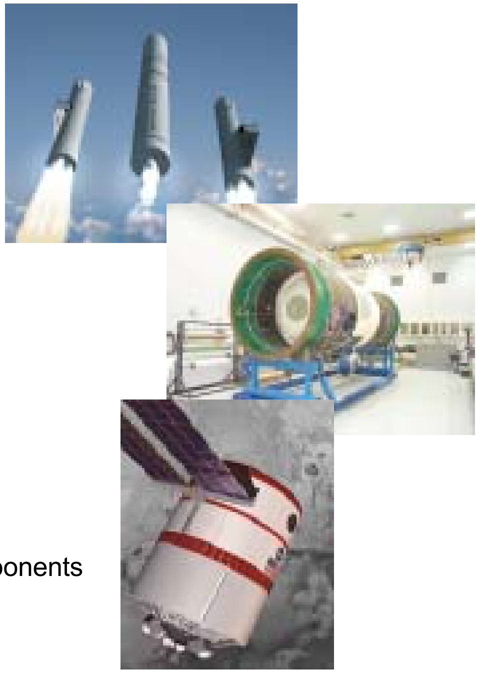
- **Point-of-Contact: Sylvia M. Johnson, Chief, Thermal Protection Materials and Systems Branch**
  - Since the early 1990’s NASA Ames Research Center has been developing a family of materials known as Ultra High Temperature Ceramics for use in passive sharp leading edge applications on future hypersonic reentry vehicles. The initial development culminated in two ballistic flight experiments, SHARP (Slender Hypervelocity Aerothermodynamic Research Probe) B1 and SHARP B2. During SHARP B1, in just 5 months from the go-ahead in early calendar year 1997, a 0.141 inch radius nose cap material was flown on a re-entry body launched by a Minuteman III missile. A follow on flight experiment (SHARP B2) was flown in September 2000 with a series of 4 leading edge strakes of 1 mm radius. During reentry the strakes were withdrawn into the re-entry body and the vehicle was recovered enabling the UHTC materials to be examined.
  - Based on the results of SHARP B2, UHTC processing was brought in-house to NASA Ames. Significant improvements were made in materials processing and properties and an improved understanding was gained of the materials’ behavior in simulated reentry environments. One cm nose radius sphere cones have been subjected to multiple exposures in a simulated reentry environment with combined exposure times exceeding 80 minutes and maximum temperatures well in excess of 2000°C. Recent work shows the significant promise of the UHTC family of materials for passive leading edge applications with use temperatures greater than 2000°C.

ARC Recent Technical Accomplishments

Ames Arc jet complex heavily used in its role as a national facility.

- **Point-of-Contact: G. Joseph Hartman, Chief, Thermo-Physics Facilities Branch**
  - The Ames Arc Jet complex continues to be heavily used as a national facility. Again this past year, the complex successfully completed around 400 tests. About 70 % of these were for the reusable launch vehicle program (e.g.X-37) and 30 % were in the planetary exploration area.

Marshall Space Flight Center



♦ Technology Applications

- Space propulsion system structures & materials
- Structures, materials, Thermal Protection Systems (TPS), and cryotanks for reusable space transportation (launch and in-space) vehicles and spacecraft
- Structures, materials and mechanisms for deployable/flexible concepts (e.g. large space optics, radiators)

♦ Technical Capabilities

- Materials contamination and space environmental effects
- Nondestructive evaluation and tribology
- Polymers and composites design, analysis, material research, manufacturing, and
- Ceramics, ablatives, and ceramic metric composites
- Metallic and Nonmetallic processes and manufacturing (e.g. Self-Reacting Friction Stir Welding)
- Metallurgical and failure analysis, corrosion engineering, and mechanical metallurgy
- Metallurgy research and processes development
- Environmental and analytical chemistry, and environmental replacement technology
- Propellant compatibility, toxic offgassing, flammability
- Project engineering and materials selection and control
- Structural dynamics, loads and durability analysis for launch vehicles, payloads and propulsion system components
- Vibration, acoustics and shock design and test criteria
- Advanced dynamic data analysis for propulsion system structural components
- Pyrotechnics for structural separation and meteoroid/debris shielding design
- Integrated structural/thermal analysis and optimization

♦ Facilities and Laboratories

- National Center for Advanced Manufacturing (NCAM)
- Large component structural testing facilities
- Structural dynamics test facilities
- Materials combustion research facility
- Materials and processes technical information system
- Space environmental effects facility
- Tribology research laboratory
- Materials Research Facility (e.g. LOX compatibility impact testing)
- Hydrogen test facility (e.g. tensile coupons)
- 3-20 foot diameter thermal vacuum chambers
- Metallurgical diagnostics facility
- Thermal spray facilities
- Joining techniques development
- Environmental and analytical chemistry laboratory
- Hot gas facility (e.g. TPS material testing)
- Combined loads and environments test facility
- Vibration test facility
- Acoustic test facility
- Large Scale Cryo-structural testing (LH2, LN2)

Directory of Technical Points of Contact at MSFC

- **SMSP Leadership Team:**

– Paul M. Munafo	Manager, Materials, Processes, and Manufacturing Department	(256) 544-2566
– Paul McConnaughey	Manager, Structures, Mechanics, and Thermal Department	(256) 544-1599

- **Technical Points-of-Contact:**

– M. Ralph Carruth	Deputy Manager, MP&M Department	(256) 544-7647
– Pete Rodriquez	Deputy Manager, SM&T Department	(256) 544-7006
– David Edwards	Leader, Environmental Effects Group	(256) 544-4081
– Robert Thom	Leader, NDE & Tribology Group	(256) 544-2517
– Chip Jones	Leader, Metallic Materials & Processes Group	(256) 544-2701
– Gail H. Gordon	Leader, Nonmetallic Materials & Processes Group	(256) 544-2726
– Steve Gentz	Leader, Project Engineering Group	(256) 544-2570
– Dennis Griffin	Leader, Chemistry Group	(256) 544-2493
– David McGaha	Leader, Manufacturing Services Group	(256) 544-1031
– Jay Medley	Leader, Special Test Equipment Design Group	(256) 544-1085
– Joseph Brunty	Leader, Structural Dynamics & Loads Group	(256) 544-1489
– Charlie Finnegan	Leader, Strength & Analysis Group	(256) 544-5447
– Sid Rowe	Leader, Structural Design Group	(256) 544-7033
– Nancy Gibson	Leader, GSE & Mechanisms Design Group	(256) 544-7149
– Larry Turner	Leader, Thermodynamics & Heat Transfer Group	(256) 544-7226
– Patrick Hunt	Leader, Thermal & Fluid Systems Group	(256) 544-2297
– Alan Patterson	Leader, Structural & Dynamic Testing Group	(256) 544-1116

MSFC Facilities and Laboratories

- **National Center for Advanced Manufacturing**
  - The NCAM is a multiple cell area which accommodates thermal and cryogenic insulation materials development and processing; automated composite manufacturing; materials and processing for environmental replacement; rapid prototyping technologies; development of subscale solid & hybrid propulsion systems; automated refurbishment technology; mechanical, thermal, physical and chemical property characterization for polymers, polymer matrix composites, adhesives, and ceramic matrix composites; adhesive development and evaluation; and high temperature ablative materials testing and evaluation
- **Large component structural testing facilities**
  - Universal test facility with three high bay test areas, large structure quasi-static load facility, component / system quasi-static load facility, hazardous structural test facility, cryogenic structural test facility
- **Structural dynamics test facilities**
  - Vibration test facility, vibroacoustic test facility, pyrotechnic shock test facility, modal test facility, and control dynamics facility
- **Materials combustion research facility**
  - Flammability, toxic offgassing and materials compatibility testing in low and high pressure/temperature environments including air, LOX/GOX, enriched oxygen and reactive fluids, test methods (NHB 8060.1, NASA-STD-6001, ASTM) and system evaluation
- **Materials and processes technical information system**
  - Mechanical and physical properties for metals and non-metals, materials test data, in oxygen environments, thermal vacuum stability, flammability, LOX/GOX and other data generated per NHB 8060.1, also stress corrosion, corrosion, and Hydrogen embrittlement data for metals
- **Space environmental effects facility**
  - Facilities for long-term exposure and materials characterization in simulated space environment
- **Tribology research laboratory**
  - Lubricant & bearing development
- **Materials research facility**
  - Alloy synthesis, processing, and characterization facilities
- **Environmental test facility**
  - Provides simulated environments for development, qualification, acceptance and research testing of space flight hardware. The facility, located in building 4619, provides the capability for thermal vacuum, vacuum bakeout, optical cleanliness bakeout, thermal humidity and thermal altitude environmental testing. The facility has 13 thermal vacuum chambers, 6 thermal humidity chambers, 3 thermal altitude chambers, and 2 clean rooms. The largest vacuum chamber, V20, is 20-feet in diameter by 28-feet long, and capable of testing 15-ton test articles. The smallest chamber is a 2-feet by 2.5-feet bell jar.

MSFC Facilities and Laboratories, continued

- **Hydrogen test facility**
  - Materials characterization in low pressure & high pressure liquid and gaseous hydrogen
- **Metallurgical diagnostics facility**
  - Hardware failure analysis, failure analysis database, electron optics facility, full service metallographic facility, and evaluation of material properties
- **Thermal spray facility**
  - Refractory composite development
- **Joining techniques development**
  - Friction Stir welding
- **Environmental and analytical chemistry laboratory**
  - Chemical analysis of liquid, gas and solid materials and contamination using a wide range of analytical methods and diagnostic techniques including: chromatography, thermal analyses, inductively coupled plasma, combustion analyses, wet chemistry, atomic absorption, mass and emission spectrometry; UV, IR, and X-ray analyses; as well as EPA methods
- **Hot Gas Facility**
  - The MSFC Hot Gas Facility (located in the east test area) is a nominal Mach 4 aerothermal wind tunnel that burns a lean mixture of air and gaseous hydrogen. HGF combustion chamber operating range is 1400 to 2200 °F at pressures of 130 to 220 psia. HGF heat flux range is 3 to 35 BTU/sf-s (convective cold wall) on test articles with a max panel size of 12x20 inches (test section cross section area is 16x16 inches). The HGF is capable of providing combined radiant and convective heating. Test specimen substrate cooling to cryogenic conditions can be provided. Infrared data is available upon request.
- **Combined Loads and Environments Test Facility**
  - Combined acoustics, pressure, thermal and cryogenic induced loads that simulate launch and on-orbit vehicle conditions.
- **Vibration Test Facility**
  - Dynamic loads including random, sine, sine-on-random, random-on-random, and transient vibration that simulate engine thrust, aerodynamic, and vehicle transient loads.
- **Acoustic Test Facility**
  - Diffuse field and progressive wave dynamic loads with +2dB overall spectra control that simulates engine acoustic and aerodynamics loads.

MSFC Capabilities: Research

Capabilities \ Applications	Aircraft		Space Transportation*				Spacecraft		
	Airframe	Engine	Pri. Str.	Cryotank	TPS	Engine	Instru't	Structure	Power
Research: TRL 1-3									
polymer synthesis and processing						MSFC		MSFC	MSFC
PMC preform and curing process dev			MSFC	MSFC		MSFC			
PMC structure-property char.				MSFC		MSFC			
light alloy synthesis & processing						MSFC			
nickel-based superalloy syn. & processing					MSFC	MSFC			
metal forming and joining process dev			MSFC	MSFC		MSFC			
metallic alloy structure-property char.			MSFC	MSFC		MSFC			
refractory composite dev. & processing						MSFC			
refractory composite struc-prop. char.						MSFC			
mechanics of nonlinear material behavior			MSFC	MSFC					
mech. & dyn. of nonlinear structural behavior			MSFC	MSFC					
durability, damage, & mech. of failure			MSFC	MSFC		MSFC	MSFC	MSFC	
sensor & measurement physics for instr.							MSFC	MSFC	
smart materials and structures							MSFC	MSFC	
orbital debris methodology			MSFC	MSFC	MSFC	MSFC	MSFC	MSFC	MSFC
probabilistic structural analysis methods			MSFC	MSFC		MSFC			
combined thermostr testing of integrated tank				MSFC					
development and test of cryogenic seals				MSFC					
an. and num. methods for high-temp PMC						MSFC			
rapid prototyping			MSFC	MSFC		MSFC		MSFC	
structural alloy development			MSFC			MSFC		MSFC	
alternative processing refinement						MSFC		MSFC	
inspection method development			MSFC	MSFC	MSFC	MSFC	MSFC	MSFC	MSFC
material combustion research				MSFC		MSFC			
refurbishment			MSFC	MSFC	MSFC	MSFC		MSFC	
foam material/systems			MSFC	MSFC	MSFC	MSFC		MSFC	
ablative insulation processing			MSFC	MSFC	MSFC	MSFC		MSFC	
environmental replacement technology		MSFC	MSFC	MSFC	MSFC	MSFC		MSFC	

* Primary responsibility for TRL 1-3 rests with Research Centers. Marshall supports activities as needed.

MSFC Capabilities: Technology Development

Applications / Capabilities	Aircraft		Space Transportation				Spacecraft		
	Airframe	Engine	Pri. Str.	Cryotank	TPS	Engine	Instru't	Structure	Power
Technology Development:TRL 4-6									
materials combustion test and evaluation			MSFC	MSFC	MSFC	MSFC			
joining techniques development			MSFC	MSFC	MSFC	MSFC	MSFC		
refurbishment			MSFC	MSFC	MSFC	MSFC		MSFC	
foam materials/systems			MSFC	MSFC	MSFC	MSFC		MSFC	
ablative insulation processing			MSFC	MSFC	MSFC	MSFC		MSFC	
environmental replacement technology		MSFC	MSFC	MSFC	MSFC	MSFC		MSFC	
non-ODC cleaning process			MSFC	MSFC	MSFC	MSFC		MSFC	
lubricant development & evaluation			MSFC			MSFC	MSFC	MSFC	MSFC
refractory composite fabrication scale-up						MSFC			
structural concepts			MSFC	MSFC		MSFC	MSFC	MSFC	
computational methods & design tools			MSFC	MSFC	MSFC	MSFC	MSFC	MSFC	MSFC
test methods for design allowables			MSFC	MSFC		MSFC	MSFC	MSFC	
polymer matrix composite fabrication			MSFC	MSFC	MSFC	MSFC	MSFC	MSFC	
structural strength tests			MSFC	MSFC	MSFC	MSFC	MSFC	MSFC	
experimental stress tests			MSFC	MSFC	MSFC	MSFC	MSFC	MSFC	
dynamics load tests			MSFC	MSFC	MSFC	MSFC	MSFC	MSFC	
experimental dynamics tests			MSFC	MSFC	MSFC	MSFC	MSFC	MSFC	
structural response measurements			MSFC	MSFC	MSFC	MSFC	MSFC	MSFC	
alternative model test methods			MSFC				MSFC	MSFC	MSFC
damping properties for CMC's						MSFC	MSFC	MSFC	
structural dynamics and loads			MSFC	MSFC	MSFC	MSFC	MSFC	MSFC	MSFC
hydroelastic fluid modeling				MSFC					
flight operations simulation tests				MSFC	MSFC				
environment testing of integrated tank sys				MSFC	MSFC				
structural modeling and assessment			MSFC	MSFC	MSFC	MSFC	MSFC	MSFC	MSFC
structural criteria			MSFC	MSFC	MSFC	MSFC	MSFC	MSFC	MSFC
probabilistic assessment			MSFC	MSFC	MSFC	MSFC	MSFC	MSFC	MSFC
fatigue and fracture assessment			MSFC	MSFC		MSFC	MSFC	MSFC	MSFC
structural test mon., interpr., and an. cor.			MSFC	MSFC		MSFC	MSFC	MSFC	MSFC
Vibration, acoustics and shock criteria eval.			MSFC	MSFC	MSFC	MSFC	MSFC	MSFC	MSFC
Thermal modeling and design assessment			MSFC	MSFC	MSFC	MSFC	MSFC	MSFC	MSFC

MSFC Capabilities: Technology Development

Applications / Capabilities	Aircraft		Space Transportation				Spacecraft		
	Airframe	Engine	Pri. Str.	Cryotank	TPS	Engine	Instru't	Structure	Power
Technology Development:TRL 4-6									
engine diagnostic data analysis						MSFC			
structural/thermal/optical integrated performance analysis							MSFC		
design optimization			MSFC	MSFC			MSFC		
survivability from orbital debris			MSFC	MSFC	MSFC	MSFC	MSFC	MSFC	MSFC
failure analysis	MSFC	MSFC	MSFC	MSFC	MSFC	MSFC	MSFC	MSFC	MSFC
NDE of raw material, joined element, subsysem., & component		MSFC	MSFC	MSFC	MSFC	MSFC	MSFC	MSFC	MSFC
verif. of compositional, environmental, & cleanliness req.			MSFC	MSFC	MSFC	MSFC	MSFC	MSFC	MSFC
evaluation of anomalous structural comp.			MSFC	MSFC	MSFC	MSFC	MSFC	MSFC	MSFC
process dev., optimization, & verification of fab. methods			MSFC	MSFC	MSFC	MSFC	MSFC	MSFC	MSFC
fab of full scale art. for manufacturing demo & hot-fire			MSFC	MSFC	MSFC	MSFC		MSFC	MSFC
material characterization for design data			MSFC	MSFC	MSFC	MSFC		MSFC	MSFC
specialized structural, coating, and environmental applications			MSFC	MSFC	MSFC	MSFC			
rapid prototyping for concept evaluation, wind tunnel testing, & accel. fab. tech.			MSFC	MSFC	MSFC	MSFC		MSFC	MSFC
simulated environment testing			MSFC	MSFC	MSFC	MSFC		MSFC	MSFC
bearing and seal testing						MSFC			

MSFC Recent Technical Accomplishments

Environmental Effects

- **Point-of-Contact: David Edwards, Leader, Environmental Effects Group**
  - The Environmental Effects Group has world class Space Environmental Effects (SEE) testing capabilities. Exposure environments include Atomic Oxygen, Ultraviolet (UV) radiation, combined electron/proton/UV, Plasma environments simulating Low Earth Orbit (LEO) and ion/plasma thrusters, and micrometeoroid/Orbital Debris impact testing. The Environmental Effects Group has generated considerable space flight data on the effects of the space environment on materials in flight experiments including the Long Duration Exposure Facility (LDEF), Shuttle experiments, the Space Portable Spectral Reflectometer (SPSR) used via EVA on Mir, Optical Properties Monitor (OPM) and the Passive Optical Sample Assembly (POSA) on Mir, and the Materials on the International Space Station Experiment (MISSE) on ISS.. Also, very stringent contamination requirements have been developed for optical flight hardware such as HST, LIS, SXI, and Chandra. Several optical techniques have been developed for quantifying surface contamination levels for hardware. These techniques are more quantifiable and easier to use than solvent based analysis.

Nondestructive Evaluation & Tribology

- **Point-of-Contact: Robert Thom, Leader, Nondestructive Evaluation & Tribology Group**
  - Tribology
    - Determined coefficient of friction of external tank spray on foam insulation (SOFI) against Orbiter tile and against leading edge reinforced carbon-carbon. Testing was performed at a gaseous pressure of 1 psi (ambient pressure is 14.7 psi) to better simulate condition of SOFI against vehicle after 81 seconds of ascent. Data used for impact analysis.
  - NDE
    - Developed methods and techniques for performing nondestructive evaluation (NDE) of external tank spray on foam insulation (SOFI). Down selected most promising methods and created qualification roadmap for implementation of NDE method to inspect external tank prior to return to flight after Columbia accident.

MSFC Recent Technical Accomplishments

Metallic Materials and Processes

- **Point-of-Contact: Chip Jones, Leader, Metallic Materials and Processes Group**
  - The Metallic Materials and Processes Group maintains world-class capability for mechanical testing, metallurgical analysis, corrosion testing and welding process development. The group recently completed the development of Design fracture properties of high-performance aluminum alloys for use in a reusable cryotank for the Next Generation Launch Technology Program. Other examples include evaluation of material properties for Shuttle components for flight rationale, and development and certification of a repair procedure for Orbiter flowliner components. Manufacturing Processes have been developed for use by contractors in producing flight hardware, such as the Friction Stir Welding Process, currently in use on the External Tank, and thermal spray coatings for corrosion protection. Production of flight and development hardware include the aluminum oxygen tank for the Fastrac program, gold-plated lenses for X-ray telescopes, and hydrogen barrier coatings for SSME Fuel Turbopump components.

Nonmetallic Materials and Processes

- **Point-of-Contact: Gail Gordon, Leader, Nonmetallic Materials and Processes Group**
  - The Nonmetallic Materials and Processes Group is responsible for the characterization and qualification of materials; research, development, and qualification of advanced processes for composites, ablatives, polymers, thermal and cryogenic insulation systems, structural adhesives, elastomeric seals, and ceramics; and fabrication of prototype and flight hardware. The group is comprised of four teams: Polymers and Composites; Ceramics and Ablatives; Process Engineering; and Composite Processes and Fabrication. Notable accomplishments include the fabrication of subscale tanks in support of advanced programs such as X-34 and SLI; fabrication of the Space Shuttle External Tank Composite Nose Cone (flight hardware); and development of material allowables for various Space Shuttle propulsion elements.

MSFC Recent Technical Accomplishments

Project Engineering

- **Point-of-Contact: Steve Gentz, Leader, Project Engineering Group**
  - Materials and Processes Technical Information System (MAPTIS) - The Project Engineering Group of Marshall Space Flight Center Materials, Processes, and Manufacturing Department's (MP&M) offers a materials and processes database, called MAPTIS, to our government and non-government customers. MAPTIS is the only approved NASA-wide Materials database which is chartered to provide materials information for all NASA facilities and NASA support contractors. The MAPTIS system receives test results data and material usage information from many different providers, such as: White Sands Test Facility, Goddard Space Flight Center, Boeing, USBI, Lockheed-Martin, Marshall Space Flight Center. The MAPTIS applications are divided into applications which are open to all users, such as the Material Properties, Material Test Results, and Standard / Commercial Parts; NASA-wide application, including Material Items Usage List, Material Usage Agreements, and Material Failure Analysis; Facility specific applications for Goddard Space Flight Center Testing Information, White Stands Test Facility Test Results information, and Marshall Space Flight Center Material Testing Results database. A web-based version will soon be available in October 2003.

Chemistry

- **Point-of-Contact: Dennis Griffin, Leader, Chemistry Group**
  - The Chemistry Group has conducted analytical and environmental chemistry analyses for projects as needed. The Group has the capability to develop new tests to characterize candidate materials and chemicals. The inorganic chemistry lab supports material analyses using standard gravimetric, titrimetric, precipitation, and calorimetric procedures. The ultraviolet/visible spectrophotometry lab is used for analysis of thin films and organic materials in water. The mass spectrometry lab enables gas analysis for chemical composition in support of cryogens and fuels used in propulsion technology. The infrared and Raman spectroscopy lab allows identification of chemical contaminants.

Impact Analysis Team

- **Point-of-Contact: Sid Rowe, Leader, Structural Design Group**
  - The Smooth Particle Hydrodynamics Computer code, SPHC, developed by Dr. Robert Stellingwerf, is being used by the MSFC Impact Analysis Team to assess and characterize impact damage to the STS 107 left wing due to a piece of External Tank foam. For the Space Launch Initiative (SLI), SPHC was utilized extensively at MSFC as an analysis tool to predict damage caused by meteoroids or orbital debris (MOD) to integrated cryotank structure. The SLI program funded hydrocode simulations and modules that included several possible variations of integrated thermal protection system (TPS)/cryo-insulation/tank wall structure. The code showed good correlation with experimental hypervelocity test results. The code was used to model Aluminum Enhanced Thermal Barriers (AETB) – an improved tile that has been flown around the SSMEs, Advanced Flexible Reusable Insulation (AFRSI), Conformable Reusable Insulation (CRI), and metallic thermal protection systems. Proof of concept of the MOD hydrocode TPS modules for the SLI program led to exploration of the use of code in the 500 fps to 1000 fps velocity impact range of the foam on shuttle wing LI 900 and LI 2000 tiles.

MSFC Recent Technical Accomplishments

Manufacturing Services

- **Point-of-Contact: David McGaha, Leader, Manufacturing Group**
  - The Manufacturing Services Group provides machining, sheetmetal, welding, electrical, surface treatment, heat treatment, and cleaning support to the research and development activities within the Center. Recent accomplishments include fabricating and assembling R&D hardware for the Environmental Control Life Support System (ECLSS), Materials Science Research Rack (MSRR), Quench Module Insert (QMI), Delta-L, and g-LIMIT projects. In addition, the Group played a vital role in rapidly manufacturing critical test hardware in support of Shuttle flight issues such as the Flowliner problem, the BSTRA Ball problem and the STS 107 Accident Investigation.

Special Test Equipment Design

- **Point-of-Contact: Jay Medley, Leader, Special Test Equipment Design Group**
  - The Special Test Equipment Design Group completed designs in support of 24-inch Solid Motor for RSRM, structural loads and cryogenic temperatures application for the Northrup-Grumman composite tank, vibration plates for ECLSS for flight qualification, assembly of the MSRR rack, qualification and certification of SRB separation bolts, certification of the launch pad hold down studs, Safe Affordable Fission Engine and Direct-Drive Gas-Cooled Reactor for the Nuclear Space Initiative, Orbital Space Plane Pad abort liquid oxygen/ethanol test program, upgrades to the Material Environmental Test Complex, Supercritical Cryogenic Injector Spray Characterization, Advanced Valve Technology, and numerous STS-107 Investigation tests.

Structural Dynamic Analysis

- **Point of Contact: Joseph A. Brunty, Leader, Structural Loads and Dynamics Group**
  - The Structural Dynamics and Loads Group completed analysis and correlation of the hot-fire battleship and gimbal flow-liner test articles in support of the Space Shuttle Orbiter Fuel Flow-liner cracking issue. Early in the investigation, ED21 analytical predictions identified the most likely root cause of the flow-liner cracking. The group developed flight failure criteria and led in the effort to choose the best repair option for a quick and safe return to flight after the crack issue had grounded the Shuttle fleet. Recent hot fire tests exhibited the predicted structural resonance contributing to the crack formation and growth and collaborated the analytical predictions. Resonance was shown at flight-like operating conditions due to a very rich flow environment propagating upstream from the low pressure fuel pump. Facilitated by low damping, both upstream and downstream flow-liners were found to resonate with significant strain levels between 900 Hz and 5,000 Hz.

MSFC Recent Technical Accomplishments

Thermodynamics and Heat Transfer Group

- **Point-of-Contact: Larry Turner, Leader ,Thermodynamics and Heat Transfer Group**
  - The Thermodynamics and Heat Transfer Group has been supporting the STS-107 Columbia Accident Investigation activity. This includes thermal analysis/testing support for the RSRM, SRB, ET, SSME, and Shuttle Systems Contingency teams. The Group also does sustaining engineering including analysis and testing support for these projects. The Group supported the JSC Aerothermodynamics Team with thermal/venting analysis of the Shuttle port wing and the TPS On Orbit Repair Team with thermal analysis and test support. The Group supported the SSME Project's STS-111 In-Flight Anomaly investigation team, Alternate Turbopump High Pressure Fuel Turbopump Pump End Ball Bearing Cover Liquid Air redesign, and the Rapid Response Hot Gas Temperature Sensor CDR. The Group is supporting the NGLT, RS-84, OSP and X-37 projects. The Group's infrared temperature measurement expertise and equipment supported the Glenn Research Center's Heated Tube test facility's propane test and this capability is also used to support on going ET testing requirements. The Group has performed thermal analysis of liquid hydrogen tank for the Helios aircraft for AeroVironment, Inc. of California. The Group has supported Boeing in the development of the Metallic Cryotank for Next Generation Launch Technology (NGLT) Vehicle. The Group supported the thermal activities Building Block-2 (Materials Selection) & Building Block-4 (Structural Design). The Group supported Boeing in the development and thermal properties testing of Thermal Protection System (TPS) and Cryogenic Insulation materials for the Metallic Cryogenic Tank. The Group supported Northrop Grumman in the thermal activities for the development of TPS and cryogenic insulation of the composite cryogenic tank. The Group has just completed the design/development/delivery of the Node 2 Thermal Control System with Alenia as the prime contractor. The Group has design/developed/and delivered the MSRR-1 TCS and has thermal control systems to the CDR level for the Quench Module Insert and other microgravity experiments to various levels of development.

Thermal and Fluid Systems Group

- **Point-of-Contact: Patrick Hunt, Leader ,The Thermal and Fluid Systems Group**
  - The Thermal and Fluid Systems Group (ED26) is responsible for thermal design, development, analysis, integration, testing, and operation of spacecraft, subsystems, components and associated thermal hardware. The group manages and operates the MSFC Environmental Test Facility and the Thermal Development Facility (TDF). The ETF provides simulated environments for development, qualification, acceptance and research testing of space flight hardware. ETF capabilities are available to government and commercial customers. The TDF provides the capability to develop and refine thermal technology and test methods required to meet the demands of next generation spacecraft. The group is engaged in numerous programs including DART, X-37, GP-B, JWST, ProSEDs, NSI/Prometheus/JIMO, Solar-B, and ISS. The group recently supported the STS-107 Columbia Accident Investigation by (a) leading the MSFC activity in providing thermal/venting analysis of the Shuttle wing for the JSC Aerothermodynamics Team and (b) providing test support. Recent thermal design and analysis work includes liquid helium dewar boiloff rates for GP-B, pre-flight predictions and mission support for ISS MPLM, ProSEDs thermal design, analyses and system-level thermal qualification test, Radiator trade studies for Prometheus, demonstrator mirror test analysis for JWST, and DART thermal test planning and predictions. The ETF completed 135 Tests were conducted in FY03operating at an average facility capacity of 270%.

MSFC Recent Technical Accomplishments

Strength Analysis Group

- **Point of Contact: Charles J. Finnegan, Leader, Strength Analysis Group**
  - The Strength Analysis Group supported the STS-107 failure investigation by active participation in the External Tank TPS debris fault tree teams and leadership of the non-TPS debris team. Detailed strength analyses were also performed in support of bolt catcher testing performed under the auspices of the SRB failure investigation team. As return-to-flight efforts were initiated, the Strength Analysis Group began development of innovative methods of analysis for structural/TPS systems for which there is no precedent. The identification of failure modes, development of analytical methodology to predict failures, and design solutions to prevent future TPS failures is the goal of the current effort.
  - A strong applied fracture mechanics capability within the Strength Analysis Group has been utilized to investigate crack growth near stress concentrations in SRB/ET forward separation bolts. Analysts within the group are employing elastic/plastic fracture mechanics theory to predict crack growth in the highly plastic zone near a notch in the separation bolt. The new analytical methodology will replace standard linear elastic fracture mechanics that has been used for life verification of this component. Revisions to inspection requirements for the bolts are expected as a result of the improved analysis technique.

Ground Systems Equipment and Mechanisms Design Group

- **Point of Contact: Nancy J. Gibson, Leader, GSE and Mechanisms Design Group**
  - The GSE and Mechanisms Design Group, ED24, designs, develops, tests, and evaluates mechanical systems including mechanical ground support equipment, flight/airborne support equipment, mechanisms, and fluid systems/components for a wide variety of spacecraft, vehicles, components, and scientific experiments. ED24 recently completed the design and qualification of an alternate transportation system to ship the Gravity Probe B satellite from the assembly facility in Sunnyvale, CA to the launch site, Vandenberg Air Force Base, using the NASA Super Guppy Aircraft. This task was accomplished on a very tight schedule, and had to meet many challenging requirements for interface, strength, stiffness, and environments.

Structural Design Group

- **Point of Contact: Sidney E. Rowe, Leader, Structural Design Group**
  - Three-dimensional CAD models were used with photographic analysis to identify the foam impact location on the shuttle Columbia. CAD design models were also used to do multidisciplinary analysis to assess damage to the orbiter. Those analyses included impact analysis and thermal-structural assessments. The group also has excellent hands-on experience with composite structures manufacturing which was a significant asset in correlating these impact analyses with needed testing.